M. N. Grant.

STUDIES IN CEREAL DISEASES

I

Smut Diseases of Cultivated Plants

Their Cause and Control

by

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DIVISION OF BOTANY
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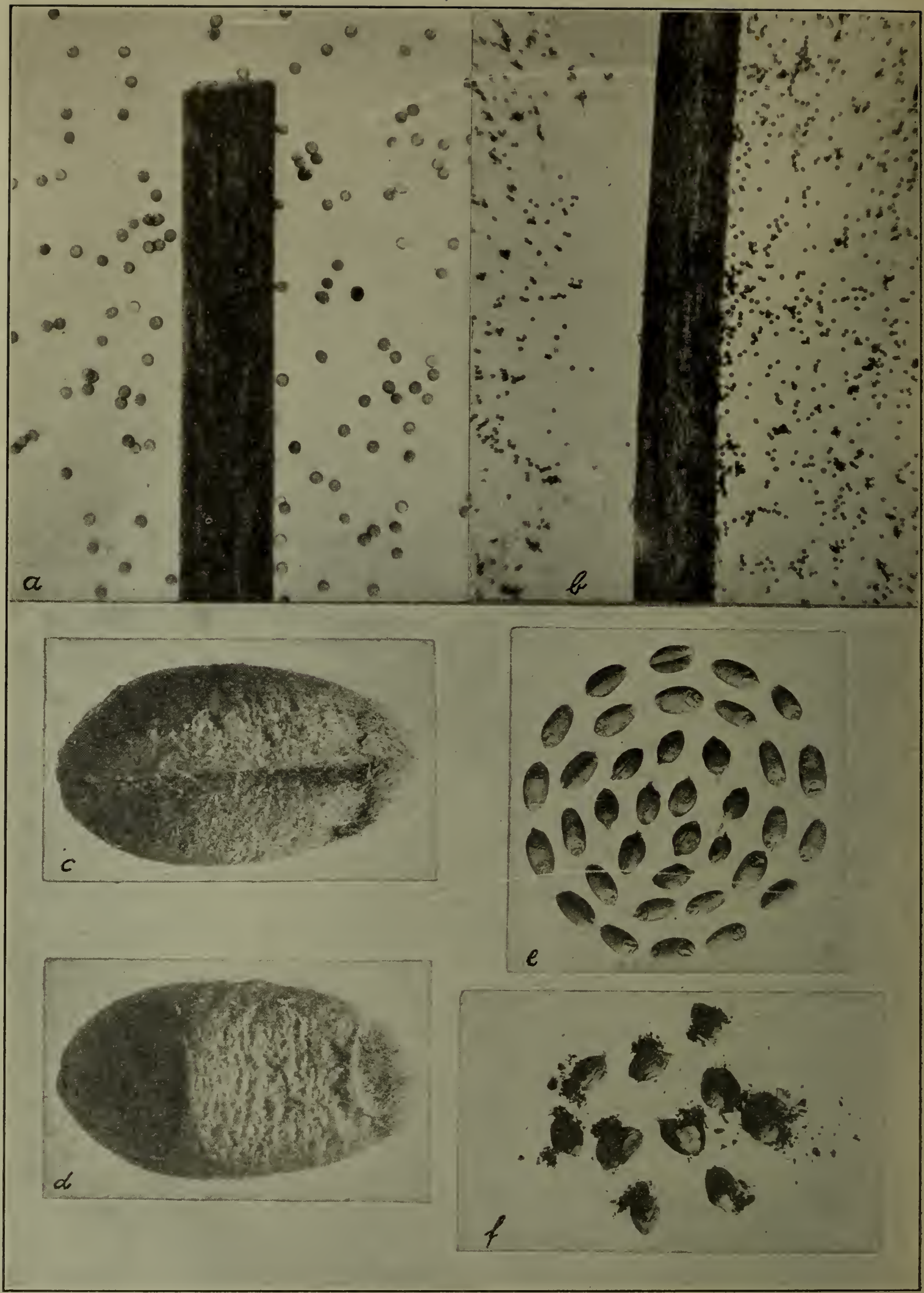

FIG. 1.—(*a*) A human hair and spores of stinking smut or bunt of wheat magnified 85 times. Eight bunt spores placed side by side measure the breadth of the hair. (*b*) A human hair and spores of loose smut of wheat at same magnification. Nineteen spores placed side by side would measure the breadth of the hair. (*c*) Wheat grain enlarged showing the side with the "crease" and the "brush" at end. (*d*) Reverse side of wheat grain showing surface wrinkles. Both magnified 7 times.

NOTE.—If the wheat grain were enlarged 85 times as was the hair, it would measure 23 inches in length. In comparison the bunt would be only 1/16 inch in diameter while the loose smut spores would be still smaller. (*e*) The outer two rows are sound grains of wheat, in the centre 11 "smut-balls" showing the appendages. (*f*) A number of smut-balls crushed; the black masses consist of millions of spores.

SMUT DISEASES OF CULTIVATED PLANTS THEIR CAUSE AND CONTROL

BY

H. T. GÜSSOW and I. L. CONNERS

PART I

GENERAL REMARKS

Smut Diseases not confined to cultivated plants.—The well-known conspicuous diseases commonly designated as " Smut Diseases " are by no means exclusively confined to cultivated or economically important members of the natural order of grasses,—among which our cereals are the most valuable,—but they also occur in other plants widely distant in relationship from the grass family. Their importance to the farmer diminishes as the properties of the plants attacked become of less economic value. For this reason, the following pages are devoted to a study of the more important forms occurring on plants of agricultural value.

" Smuts " caused by microscopic fungi; their nature and action on the host plant.—All smut diseases are caused by minute parasitic plants known as fungi. Many of these minute plants—popularly referred to as moulds—are of decidedly destructive habit, owing to their parasitic mode of life. They are forced to live parasitically, since fungi are incapable of manufacturing their own food, and, therefore, depend for their sustenance upon ready prepared food, which they find in the tissues of the plant—or host plant, as it will be called for our purpose—on which they live. As a result of such relationship, they either seriously interfere with, or frustrate altogether, the purposes for which the plants are cultivated, or they may finally cause the death of the plant on which they depended for their livelihood. The various fungi causing smut diseases are destructive parasites and, frequently, entirely prevent the production of grain. The smuts, like other related fungi, consist of delicate vegetative hair-like hyphae—collectively spoken of as the mycelium—which penetrate the tissues of the host and absorb nourishment from them. After a period of development in the host tissues, the mycelium produces an abundance of reproductive bodies called spores. Usually the smut fungi cause so little disturbance within the cells of the host that no outward symptoms are perceptible until spore formation occurs. In cereal smuts this takes place about heading time, the spores replacing most of the normal tissue of the head. In corn smut, spores may be formed at any time in masses of varying sizes on any of the above-ground parts of the plant. The spores appear in all cases as blackish or sooty masses.

Fungus spores are comparable to seeds of more highly organized plants inasmuch as they reproduce their kind. They are not, however, seeds in the true botanical sense. They are minute, round or roundish plant-cells, finer and lighter than road-dust or similar substances easily carried in the air.

Methods of spore dispersal.—On account of their minute size the spores are readily caught up by slight air currents and may be carried for many miles. This seems to be the most important method of spore dissemination among the loose smuts, where wind-borne spores cause infection at flowering time. In the case of the covered smuts, many of the spore masses are broken up in the

threshing machine and issue from it as black clouds of dust. Heald and George[1] found in the State of Washington that a spore-trap, located a mile and a half from the nearest threshing machine, collected over 10,000 spores per square inch during one week. Rust spores also have been found in the air in great abundance, and some have been located even at a height of three miles.[2] Evidence collected by Pennington[3] indicated that the spores of white pine blister rust had been carried a distance of 150 miles in British Columbia.

Although wind is an important agent in the dissemination of smut spores, it is not, however, the only one. The hairiness of the wheat grain (see fig. 1 c, d,), the small cracks or deep lines in the hull of the oat, the rough seed-coat of barley provide adequate means for the adhesion of spores. By sowing such infected seed the disease is also spread. Or the smut spores may ultimately reach the soil by way of infected manure, farm implements, or machinery covered with spores. Clean grain may become contaminated by being stored in bins or bags which previously contained smutted seed. In this connection it should be pointed out that care should be taken to use clean bags, especially for seed that has been treated, to prevent re-infection with smut spores. The old bags that have contained smutty grain may be freed from the spores by dipping them into a strong formalin solution, or into boiling water. After drying, they may be used again with safety.

Threshing machines, an important agency responsible for the spread of smut diseases.—Undoubtedly the practice in vogue of moving threshing machines from one farm to another is responsible to a considerable extent for the spread of smut diseases and their introduction into farms previously quite free from smut. A machine, which has been used for threshing smutted wheat, is so fully infected with spores that any grain subsequently threshed will become contaminated, unless the machine is properly disinfected after use.

The method recommended for the disinfection of the threshing machine is simple and effective. After sweeping the machine, inside and out, to get rid of weed seeds, the foreman of the threshing gang should immerse some old bags or sacking in formalin—one pound to one gallon of water—and place them inside the machine, after which all openings should be closed or covered up to retain the formaldehyde which evaporates. If properly air-tight, the fumes will very effectively destroy the vitality of any smut spores, while the machine is travelling from one farm to another. After five to six hours of fumigation, the inside of the machine will contain no living smut spores. The outside of the machine, wagon, racks, and any implements, etc., in use may be rapidly sterilized by means of an ordinary knapsack sprayer filled with the formalin solution mentioned before. The whole procedure will not require more than one-half hour after a little experience, and would cost only a slight amount.

The farmers should insist on seeing this treatment carried out, and the thresher should be provided with a card setting forth that this treatment was carried out before leaving the farm, which card should be signed by the farmer and be demanded by the next farmer on the list, when the machine arrives on his premises. Farmers by exercising such care would greatly aid in the reduction of smut diseases throughout important grain-growing areas.

Vitality of the smut spores.—(*a*) NATURAL.—The spores of certain smut diseases which reproduce entirely by spores, as, for instance, stinking smut of wheat, covered smut of barley, and the oat smuts, are very long-lived; under certain favourable circumstances, the spores may retain life for as long as twelve years.[4] In a dry condition, they are also exceedingly resistant to frost. It is

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[1] Heald, F. D., and D. C. George. Wash. Agr. Exp. Sta. Bul. 151. 1918.
[2] Stakman, E. C., et al. Jour. Agr. Research 24:599-605. 1923.
[3] Pennington, L. H. Jour. Agr. Research 30:593-607. 1925.
[4] Woolman, H. M. and H. B. Humphrey. U.S.D.A. Dept. Bul. 1239. 1924.

evident then, that infected grain cannot be freed of smut by storing, for the germinative power of seed would be greatly impaired before the infective power of the spores was lost.

How long loose smut spores retain their viability has not been ascertained, but Stakman[5] found that they germinated as well after ten months in storage as they did when first collected. Until recently, the longevity of these spores was considered of little consequence, as newly produced spores were supposed to cause infection of the grain at flowering time. Tisdale and Tapke,[6] however, have succeeded in obtaining infection in barley by inoculating dehulled seed with loose smut spores. Their work points to the possibility of infection occurring under field conditions from spores on the seed, and consequently the longevity of the spores has assumed a real importance and requires careful investigation.

(*b*) Vitality of Spores passing through bodies of animals.—The next point to consider is the viability of spores which have passed through the bodies of animals fed on smut-infected food. This point is of practical importance, since, if such spores remain alive, they may be disseminated over considerable areas when the manure in which they occur is spread on the soil. Naturally, the most important smut fungi concerned in this connection are those causing seedling infection, as, for instance, stinking smut of wheat. Partly for this reason, and partly because these spores may be obtained in sufficiently large quantities to render feeding experiments of value, the spores of this fungus are generally used for the purpose. The experimental results[7] on this subject may be summarized as follows: "The passage, through the bodies of animals of all kinds, of stinking smut spores resulted in destroying the germination of the great majority. Only those passing through pigs retain their germination to a greater degree."

Hence it will be seen that there still exists some danger from the spreading of these diseases by spores ingested by animals and contained in their manure.

Not only passage through animals but other agencies also are known to destroy the spores. Piemeisel[8] found that the spores of corn smut failed to germinate after being stored a few weeks in a silo. He thought it probable that, during the process of fermentation, organic acids were formed which destroyed the vitality of the spores.

Is smut-spore-infected food injurious to animal health?—There have been discussions from time to time in the agricultural press with reference to the probable injuries to live stock fed on smutted grain or food. Important text-books even now point out the danger of such practice. It is said that smutted grain, both seeds and straw, whether dry or green, is injurious. Disturbances of the digestive organs, loss of flesh, flow of saliva, paralysis of the hind-quarters and of the muscles of the mouth and throat, are the symptoms not infrequently recorded; death even has been reported.

The results obtained, however, from careful inquiry and experimentation do not confirm this serious arraignment. In an extensive investigation[9] with all the ordinary farm animals, pigs, cows, horses, sheep, rabbits, chickens, and pigeons, not a single instance was noted where animals were definitely sick as a consequence of their having eaten food contaminated with smut. On the other hand, the authors conclude that food contaminated with smut spores cannot be declared harmless under all circumstances, and, therefore, it cannot be recommended for feeding; especially should pregnant animals and those naturally subject to slight intestinal troubles receive no such food.

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[5] Stakman, E. C. Minn. Agr. Exp. Sta. Bul. 133. 1913.
[6] Tisdale, W. H. and V. F. Tapke. Jour. Agr. Research 29:263-284. 1924.
[7] Honcamp, Fr. and H. Zimmermann. Centbl. Bakt., etc. Abt. II, 28:22-24, p. 600. 1910.
[8] Piemeisel, F. J. Phytopath. 7:294-307. 1917.
[9] Honcamp, Fr. and H. Zimmermann. Centbl. Bakt., etc. Abt. II, 28:22-24, p. 596. 1910.

In discussing this subject McAlpine[10] points out that the well-known boils of corn contain the same alkaloid as ergot, and the fluid extract is used in a similar manner. The truly poisonous character of ergot and its peculiar action on the uterus when given to pregnant animals are well established. But, on the other hand, smut boils on Chinese water rice (*Zizania latifolia*), caused by the smut fungus *Ustilago esculenta* P. Hen., are an important article of food in China.

As regards oat smut,[11] the following opinion is given: When abundant in a crop which is cut for green feed, oat smut may cause irritation and congestion. A number of fatalities amongst cattle in northern Alberta have been attributed to this. In Montana, a lot of cows were fed on smutty hay, and within twelve hours after the first feed, one-half of them died with symptoms of gastritis and cerebral excitement. No more of the hay was fed, and no more deaths resulted. A post-mortem examination showed the stomach much distended.

We find these opinions more or less unanimous on the point that food contaminated with smut is at any rate unwholesome, and, although the matter is not definitely cleared up, we advise farmers not to run any risk of losing animals by giving them food of a so decidedly suspicious nature.

REPRODUCTION OF SMUT DISEASES AND INFECTION OF HOST PLANT

We have already discussed the production of smut spores and their means of dispersal. The time of their dispersal involves the question of reproduction as well as of the mode of infection of plants. When the seed of an ordinary annual plant has ripened, the plant has fulfilled its function of reproduction, and thereupon dies. The continuance of this species of plant rests then with the seed. Likewise, when the smut spores have ripened, vegetative life of the fungus has come to a termination, and reproduction depends upon the spore reaching eventually an environment favourable for its development into a new generation. The new generation of a given smut fungus will appear to us in the form of one of the well-known smut diseases. After being produced, the spores of some smut fungi require to reach the soil in order to propagate their kind. This purpose is accomplished in stinking smut of wheat, covered smut of barley, naked and covered smut of oats and others, by the spores adhering to the outside of the grains, and thus being sown when the grain is sown. When finally the spore has reached the soil it germinates and produces a stout, short piece of mycelium from which secondary or even tertiary spores may develop and these attack the young grain seedling by means of infection threads. This mode of infection is known as seedling infection.

The manner of infection is different in the loose smuts of wheat and barley. In these cases the spores are ripe at the time the grains are in flower, and are carried by the wind to the pistils of the flowering grain, where they germinate in a manner similar to that of the pollen-grain when fertilizing the ovule. The germ-tubes push their way into the ovaries of the flowers where they remain dormant in the form of delicate mycelial threads without preventing the formation of the kernels which, though containing the germ of disease, are apparently quite normal. Plants grown from such seed will eventually show the loose smut disease. This mode of infection is termed flower infection.

A third method of infection occurs in Indian corn. Here infection may occur through young and tender parts at any stage in the development of the plant, instead of being limited to the seedling or flowering stages, as discussed in the previous cases.

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[10] McAlpine, D. The Smuts of Australia, Melbourne. 1910.

[11] Willing, T. N. Plants Injurious to Stock. Dep. Agric. Northwestern Territories, Bul. 7. 1903.

The importance of a knowledge of these different modes of infection becomes apparent when methods of controlling the various smut diseases are considered. A treatment that controls effectively one group of diseases may be quite ineffective when applied to another group. Successful control of bunt and covered smuts is afforded by treating the seed with formalin or copper carbonate; of loose smuts, by the hot-water treatment; but no satisfactory seed treatment exists for the control of corn smut. Each treatment will be discussed separately in Part II of this bulletin.

FACTORS INFLUENCING INFECTION WITH SMUTS

Smuts, like all other plants, are influenced profoundly in their development by environmental conditions. Especially is this noticeable in the case of the covered smuts of cereals. It not infrequently happens that seed of a susceptible variety of grain, though heavily smutted at the time of sowing, produces a crop wholly free from smut. In addition to such field observations there is experimental evidence which indicates that plants frequently escape infection, not as a result of resistance in themselves, but because conditions during the early growth of the plants were unfavourable for the development of the fungus.

Time of Planting.—It has been known for some time that the amount of smut in a field at harvest was greatly influenced by the time at which the seeding was done. Two cases reported by Munerati[12] may be cited to illustrate this point: A large field of winter wheat which had been sown about the end of October was heavily attacked by stinking smut (about 60 per cent), while the adjacent fields belonging to the same farmer, sown with the same variety of wheat, and treated in a similar manner, but seeded early in October, showed no sign of infection. Another farmer had sown spring wheat without previous treatment for smut in one field at the beginning of February, and in another at the middle of March. At harvest time 30 per cent of the first sowing and less than 5 per cent of the later sowing were infected with smut.

Munerati accordingly investigated the problem experimentally and obtained the results given in table 1.

TABLE 1.—THE INFLUENCE OF TIME OF SOWING ON BUNT INFECTION

Date of sowing	Percentage of infected wheat	
	Treated	Untreated
October 11	0	1
October 21	0	3
November 10	1	10
November 22	4	90
February 10	2	30
March 10	0	5

These results indicate that the varying climatic conditions which prevailed at the times when the sowings were made had a marked influence on the resulting infection. Munerati by way of infection states: A grain, which is covered with smut spores (*Tilletia*) and has not been treated with solutions, escapes the attack of the parasite if sown early, but the same grain will, on the contrary, be infected by the disease, if sown when the temperature is low and the

[12] Munerati, O. and H. Hitier. Jour. d'Agric. pratique. Yr. 76, Vol. II, No. 42, pp. 494-496. 1912. Abstr. in Int. Inst. Agr. Bul. Agr. Intelligence and Pl. Diseases. Yr. 3.12:2746-2748. Dec., 1912.

plant is making little growth. The contrary is the case in spring wheat. In practice, the later in the autumn and the earlier in the spring wheat is sown, the more necessary it is to treat the grain with fungicides. Similar results on the influence of time of planting on infection have been reported by Woolman and Humphrey.[13] They found that, under conditions prevailing in the State of Washington, the later the sowing was done in the fall, the greater was the amount of bunt that developed in the crop. This was true for all except the last few sowings, in which cases, the amount of smut fell off sharply. In the spring the earlier sowings had much more bunt than the later ones.

Temperature of soil.—Although a number of factors may be responsible for the influence of the time of planting on the resulting infection, the temperature of the soil does affect bunt infection. Munerati[14] planted bunted wheat in beds held at several different temperatures. After forty days the seedlings were considered to be immune from subsequent attacks. They were then set out in the open field and grown to maturity. The results of this experiment are given in table 2.

TABLE 2.—INFLUENCE OF SOIL TEMPERATURE ON INFECTION WITH BUNT

Temperature in degrees Fahr.	Plants matured	Plants infected	Percentage of infected plants
71·6—77·0	604	0	0
50·0—53·6	940	143	15·2
35·6—39·2 (20 days) then 71·6—77·0	247	0	0
35·6—39·2 (20 days) 50·0—53·6 (7 days) then 71·6—77·0	329	86	24·6
35·6—39·2 (40 days)	235	0	0

From these results and from those of other investigators, we may say that wheat is not infected at low temperatures, but as the temperature of the soil is raised the number of plants that become infected increases until, at a temperature of from 46° to 50° F., the maximum infection takes place. A further increase in temperature causes a decrease in the amount of infection until finally, at 70° F., wheat completely escapes attack.

These results on the influence of soil temperature on the infection of wheat with bunt can be readily understood if we consider the influence of temperature on the germination of wheat and of bunt spores. In the case of wheat the lower the temperature the slower is the germination. Wheat sown in experimental plots and kept at a temperature of from 34° to 36° F., that is a few degrees above the freezing point, began to germinate, but its progress was very slow. When the wheat was kept at 77° F., germination took place after twenty hours; and the period from germination to the production of the first leaf, which pushed through the protective sheath, was considerably shortened by the higher temperature.

Bunt spores (*Tilletia*) on the other hand do not start into activity until the temperature of 41° F. is reached. They germinate most readily at from 64° to 68° F., and will not germinate at all above 77° F. Therefore, at the very low temperature just about freezing, the wheat will germinate slowly but the bunt spores will not germinate at all. At from 46° to 50° F., the wheat still germinates slowly while the bunt spores germinate freely. The germ-tubes penetrate the young seedlings and, since the fungus is growing much more

[13] Woolman, H. M. and H. B. Humphrey. U.S.D.A., Dept. Bul. 1239. 1924.

[14] Munerati, O. Rendic. Accad. Lincei 32; series 5 and 6:285-289. 1923. Abstract in Rev. Appl. Myc. 3:511. 1924.

rapidly than the seedlings, it readily reaches the growing point and infection is assured. Above this temperature the germination of the wheat and its subsequent development takes place so much more quickly than the germination and the development of the bunt spores that infection is prevented, since the infection of the wheat plant can take place apparently only during the short period from the beginning of germination to the point when the first green leaf pushes through the colourless sheath in which it is enclosed.

The temperature conditions which have been discussed for bunt of wheat do not necessarily hold for the other smut fungi. When we come to study them the most favourable temperature for infection may be quite different. While oats respond to temperature in practically the same way as wheat, a heavy infection of oats with either the loose or covered smut may take place at temperatures from 60° to 72° F. [15, 16] at which temperature bunt of wheat is almost entirely inhibited. This difference in response to temperature between spores of bunt and of the oat smuts may be due to the fact that the spores of the oat smuts germinate from two to three times more rapidly than those of the bunt fungus, when both are placed under favourable conditions.

Soil moisture.—The influence of soil moisture on smut infection is not as well understood as the influence of soil temperature. In general, a soil with a high moisture content is unfavourable for smut infection, while a comparatively dry soil is conducive to heavy infection.

Type of soil.—The type of soil in which smutted grain is sown greatly influences the degree of infection in the resulting crop. Gassner[17] has presented some interesting experimental data on this subject. He divided into six lots some wheat which was heavily loaded with bunt spores. Five of these lots were subjected to various treatments and one was left untreated as a check. Seed from each of these lots was then sown in clay, sand, garden soil, and peat, respectively. The percentakes of bunt that developed are given in table 3.

TABLE 3—INFLUENCE OF TYPE OF SOIL ON INFECTION WITH BUNT

Treatment	Percentage of Infection			
	Clay	Sand	Garden soil	Peat
Untreated	1·0	29·2	30·5	24·2
Formalin	0	0	4·6	3·7
Uspulun	0	trace	2·4	1·7
Segetan-neu	0	0	1·2	0
Copper oxide ammonia	0	0	0	0·6

It is evident from these data that the physical make-up of the soil exerted a marked influence on infection. The heavier types of soil were unfavourable for infection with bunt. This combined with the fact that a high percentage of moisture in any soil is likewise unfavourable to bunt infection, suggests that the factor which is responsible in both cases for the reduced infection is lack of air. This idea is supported by additional experimental data[18] which indicate that the spores of the bunt fungus (*Tilletia Tritici*) will not germinate unless a relatively large amount of air is available.

[15] Bartholomew, L. K. and E. S. Jones. Jour. Agr. Research 24:569-575. 1923.
[16] Reed, G. M. and J. A. Faris. Am. Jour. Botany 11:579-599. 1924.
[17] Gassner, G. Angew. Bot. 7:80-87. 1925. Abstract in Rev. Appl. Mycl. 4:599-600. 1925.
[18] Woolman, H. M. and H. B. Humphrey. U.S.D.A. Dept. Bul. 1239. 1924.

Influence on infection of the number of spores on the seed.—In addition to environmental conditions, the number of spores which are present on the seed at the time of germination influences the resulting infection in the case of covered smuts. Since any one spore is capable of initiating an infection, the greater the number of spores present, the greater will be the chances of infection taking place. Data presented in table 4[19] indicate the influence of the spore-load on bunt infection in an experiment with two wheat varieties. The two varieties, Prelude and Marquis, were artificially smutted with bunt spores at five different rates. In each case the percentage of infected plants increased rapidly as the spore-load was increased.

TABLE 4.—EFFECT OF RATE OF SMUTTING OF THE SEED ON PERCENTAGE OF BUNT IN THE CROP

Rate of Smutting*	Percentage of bunt	
	Marquis	Prelude
1:30	42·2	87·3
1:100	37·3	82·5
1:500	22·3	40·2
1:1000	10·0	27·2
1:2000	7·8	11·3

*1:30 indicates 1 part of smut to 30 parts seed by weight.

However, as Munerati[20] points out, it is really the number of spores which are localized over the embryonal zone that is important in relation to infection, rather than the total spore-load on the whole seed. He has shown clearly that spores which are caught in the brush are too remote from the embryo to play any significant part in causing infection.

SMUT SPORES IN THE SOIL

The discussion up to this point has dealt only with infections arising from spores which adhered to the seed. There is, however, another possible source of infection, namely from spores in the soil. In the case of the loose smuts this possibility of infection does not exist, since infection occurs practically only at flowering time. But in the case of the covered smuts, especially bunt, infection from spores in the soil causes serious losses in certain localities. This is particularly true in the Palouse valley of Washington and Oregon. In this district, according to Woolman and Humphrey,[21] much of the land is fallowed during the summer. Harvesting operations begin about the first of July. Bunt spores are liberated by this operation and are scattered over the fallowed ground by the wind. At this time the soil is very dry and remains so until September when the fall rains set in. Usually seeding begins after the first good rain. The smut spores and the wheat germinate together and heavy infection results. All the viable spores germinate within five or six weeks and, consequently, infection from spores in the soil cannot take place in the spring.

In Western Canada, conditions are considerably different. As a rule threshing is done so late in the fall that the soil is too cold to permit the germination of any spores which have been set free by this operation. These loose spores, as well as the spores in smutted heads and unbroken bunt-balls

[19] I. L. Conners in Report of the Dom. Botanist for the year 1924. Ottawa, 1925.

[20] Munerati, O. Rencid. Acad. Lincei 31: ser. 5a:125-129. 1922. Abstract in Rev. Appl. Myc. 2:262-263. 1923.

[21] Woolman, H. M. and H. B. Humphrey. U.S.D.A. Dept. Bul. 1239. 1924.

which have fallen to the ground during harvesting, may remain viable throughout the winter and cause infection the following year. However, the marked effectiveness of seed treatments in controlling bunt indicates that infection from spores which have overwintered in the soil does not occur commonly in Western Canada. In Eastern Canada there is an abundance of moisture throughout the fall and the temperature is usually not low enough to prevent the germination of the spores. Probably on account of these conditions bunt spores do not overwinter there.

VARIETAL RESISTANCE OF CEREALS TO THEIR RESPECTIVE SMUTS

From these observations it is evident that the mere failure of infection to occur in any specific instance does not necessarily indicate that the variety concerned is highly resistant to the smut in question. The variety may have merely escaped infection. In spite of this, however, each particular variety of wheat, oats, or barley does possess a perfectly definite degree of resistance or susceptibility to each smut, and there is the greatest variability in the resistance of different varieties of the same cereal to the same smut fungus. For instance, Marquis wheat is highly resistant to loose smut and is moderately resistant to bunt, while Kota, on the other hand, is highly susceptible to loose smut and moderately susceptible to bunt. Some varieties of common oats, for example, Black Mesdag, Culberson, Joanette, and Siberian, have been reported resistant to both loose and covered smuts of oats.[22] The ideal solution of each particular smut problem is, therefore, the development of a variety of the host plant which is resistant and which is at the same time satisfactory from an agronomic standpoint. This requires the combined effort of the plant pathologist and the plant breeder, and it is a line of investigation of much promise. Two examples will be cited to indicate the progress which is being made in this direction. The United States Department of Agriculture[23] has obtained by selection an oat variety which is immune from covered smut and which has highly-yielding ability and fairly satisfactory kernel characters as well. This variety has been named Markton. It yields particularly well in the Pacific Coast States and it may also be suitable in the Middle West. Reed[24] has reported on a cross between Black Mesdag and *Avena nuda* var. *inermis*. Black Mesdag is a black, hulled, common oat which is resistant to both loose and covered smut, while the other variety is a hulless oat, highly susceptible to both smuts. By inoculating the hybrid seed with spores of loose smut, Reed was able to isolate from this cross both hulled and hulless strains resistant to the smut. Similar results would probably have been obtained if covered smut had been used.

PHYSIOLOGIC FORMS IN THE SMUT FUNGI

In 1924 Reed[25] made an exceedingly important discovery regarding the fungi which cause the loose and covered smuts of oats. He had two collections of the loose smut of oats which appeared identical but which had come from two different sources, the one from Missouri, the other from Wales. He inoculated separate lots of seed of a large number of oat varieties with each of these collections and grew the seed under controlled conditions which were very favourable to infection. Since the smuts were apparently identical, it would be expected that the oat varieties would react in the same manner to each of them. Such

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[22] Reed, G. M., et al. U.S.D.A. Dept. Bul. 1275. 1925.
[23] Stanton, T. R., et al. U.S.D.A. Dept. Circ. 324. 1924.
[24] Reed, G. M. Mycologia 17:163-181. 1925.
[25] Reed, G. M. Am. Jour. Botany 11:483-492. 1924.

was not the case; for, while both collections of smut were able to infect many of the common oat varieties, the Missouri collection was able also to infect the hulless varieties, and the collection from Wales was not. Repeated trials confirmed the fact that these seemingly identical collections of smuts actually differed in regard to the varieties they were able to attack. Since these smuts appeared exactly alike even under the microscope, the difference between the two must have been solely physiologic. Such strains of a fungus are known as physiologic forms. In covered smut of oats Reed was able to distinguish two such physiologic forms. Subsequently Faris [26] found five forms in the covered smut of barley, and it is quite likely that physiologic forms will be demonstrated in still other smut fungi.

The existence of physiologic forms in the smut fungi is of very great significance in relation to the development of resistant varieties. If Reed had worked only with the Wales collection of loose smut of oats, he would have concluded that the hulless varieties were resistant. He might even have used these varieties as resistant parents in making artificial crosses designed to develop a hulled variety which would be resistant to loose smut. The effort would have been futile, for obviously the newly developed variety would have been completely susceptible wherever the other physiologic form was present. This illustrates the significance of physiologic forms and indicates the necessity of making a thorough study of the occurrence and behaviour of these forms in connection with each particular smut problem. Only in this way can resistant varieties be chosen or developed with any assurance that their resistance will be adequate in all localities and at all times.

LOSSES CAUSED BY SMUTS

Smut diseases cause heavy losses wherever cereal crops are grown. Two distinct items are involved in these losses. In the first place, there is an actual reduction in yield. This is due to the development of smutted heads in place of normal ones, and the loss from this source may range from a trace to the bulk of the crop, depending on the percentage of smutted heads present. In the second place there is an additional loss sustained in marketing smutted grain. Dockage is universally charged on smutted grain at elevators, and this amounts to a very considerable item if smut is present in appreciable quantities.

In the United States careful estimates of losses from smut have been made for a number of years. For the six years, 1919 to 1924 inclusive, the average annual loss for the principal grain crops was over $100,000,000.[27] This figure represents a loss of 2·5 per cent of the total crop value for this period. In Illinois[28] a detailed survey was made in 1923 to determine the loss caused by bunt. The estimated loss from reduction in yield was $2,275,000, with a further loss of $100,000 for dockage.

In Canada careful estimates of smut losses[29] are available only for the last few years. According to the estimated losses from smut for the years 1920 to 1923 inclusive, which are presented in table 5, the average annual loss to the Canadian farmer from this source was over $12,500,000. This, a conservative

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[26] Faris, J. A. Phytopathology 14:537-557. 1924.

[27] The value of the crop was calculated from the farm prices for the United States on Dec. 1st of each year as given by the U.S.D.A. Year Book, 1924. The loss was then determined by totalling the individual losses for each smut as reported in the U.S.D.A. Plant Disease Reporter Supplements 12, 18, 24, 30, 36 and 43 for the years 1919 to 1924 inclusive.

[28] U.S.D.A. Plant Disease Reporter Supplement 35. 1924.

[29] The estimate of losses from smut diseases in Canada was made from Survey of Plant Diseases in Canada, Vols. 1 to 4 for the years 1920 to 1923. The value of crop was obtained from the Monthly Bull. of Agr. Statistics Bureau of Statistics 8: Part 197. 1925.

estimate, is a very substantial loss and is all the more to be regretted since it could readily be reduced to a negligible amount through seed treatment.

TABLE 5.—AVERAGE ANNUAL LOSSES FROM SMUT DISEASES IN CANADA FOR THE YEARS 1920 TO 1923 INCLUSIVE

Kind of grain	Value of the crop	Estimated percentage destroyed by smut	Losses
Wheat	$331,677,000	1·2	$ 3,980,000
Barley	36,745,000	3·0	1,102,000
Oats	199,206,000	3·4	6,773,000
Corn	48,818,000	2·0	976,000
Average total loss			$12,831,000

It will be noticed in table 5 that a loss of $3,980,000 is reported from the loose and stinking smuts of wheat for the years 1920 to 1923. Although this loss is still much higher than it should be, it is insignificant when compared with the losses which were suffered from bunt alone, during the early period of settlement in Western Canada. Previous to 1900, cases in which bunt destroyed 30 to 40 per cent of the crop were frequently reported. The disease was alarmingly serious and threatened to be a limiting factor in wheat production in Western Canada. Subsequently, however, through the development of a successful seed treatment, bunt became less and less serious, until to-day it has practically disappeared from the better-farmed districts, and survives only as an indication of careless farming practices.

Canadian farmers are suffering also a yearly loss of over six million dollars from oat smuts. Since, as will be seen from the subsequent discussion, oat smuts are readily controlled by standard seed treatments, this loss represents a sheer waste for which there is absolutely no excuse.

A careful consideration of the data presented on losses due to smuts should convince any farmer of the advantage of consistent seed treatment with all his cereal crops.

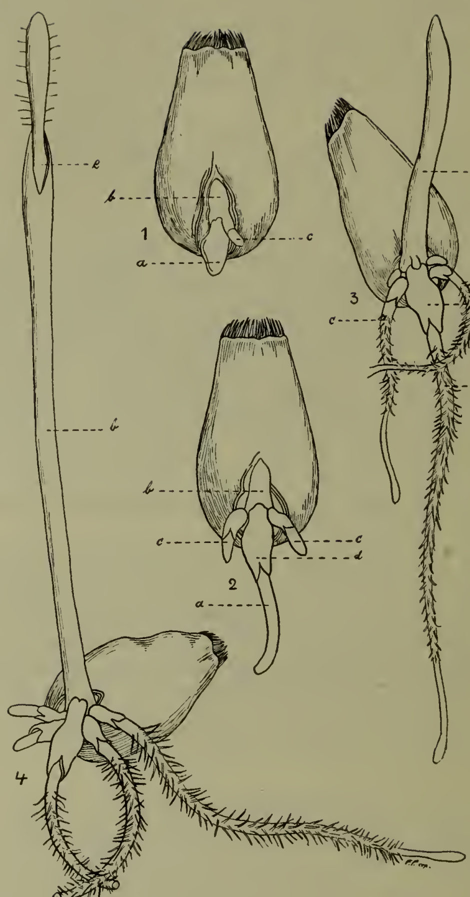

FIG. 2.—Showing various stages of germination of wheat during which infection by stinking smut spores may take place; (*a*) primary rootlet; (*b*) stem; (*c*) secondary rootlets; (*d*) protective sheaths; (*e*) point where first green leaf pushes through the sheath, after which stage no infection occurs. (Drawings copied from diagrams, "The life of the wheat plant" issued by the Royal Agricultural Society of England, prepared by Francis Bauer under supervision of Dr. Wm. Carruthers, F.R.S.)

PART II

DESCRIPTION OF VARIOUS SMUT DISEASES, THEIR LIFE-HISTORY AND TREATMENT

BUNT OR STINKING SMUT OF WHEAT

(Fig. 3; b, c)

One of the striking characteristics of bunt or stinking smut of wheat is the peculiar, decidedly unpleasant odour it imparts to the infected grain. Even with grain but lightly infected the odour is perceptible, especially when a person comes from the open air into a car or granary where bunted wheat is stored. This odour reminds one of herring brine, and is due in both the smut and the brine to a volatile alkaloid, trimethylamine. Besides the disagreeable odour the brush is blackened by the spores, and unbroken bunt balls are often present.

Bunt or stinking smut of wheat is caused by two closely related, but distinct, smut fungi, a smooth-spored species (*Tilletia laevis*) and a rough-spored species (*Tilletia Tritici*). The roughness of the spores is due to the reticulated or netlike markings on the surface of the spore.

In the United States the smooth-spored species seems to be the more common of the bunt fungi. Both species are found in Michigan. In Illinois[30] only *Tilletia laevis* was found after a careful survey in 1923, when the loss from bunt was estimated at over $2,000,000. West of the Rocky Mountains *Tilletia Tritici* is by far the more prevalent, especially in the Palouse valley of Oregon and Washington where *Tilletia laevis* is still unknown.[31]

In Canada the rough-spored species is the more common. However, the smooth-spored species is also known. Through the kindness of the Chief Grain Inspector at Winnipeg samples were obtained from all cars of grain that were found to be smutty. These samples were from cars coming from all parts of the grain-growing sections of the Prairie Provinces and were drawn during a period of about one month while the grain movement was at its height. In 10 of the 27 samples obtained from the Prairie Provinces *Tilletia laevis* predominated, while in the other 17 *Tilletia Tritici* was the more common. Moreover, the samples showing mostly *Tilletia laevis* were from places south of a line joining Calgary, Alta., and Winnipeg, Man. North of this line *Tilletia Tritici* predominated or occurred alone. Bunt seems to be far more abundant in Alberta than in the other two provinces. Of the 27 samples collected 20 came from Alberta, 6 from Saskatchewan and 1 from Manitoba. In the States contiguous to the Prairie Provinces, bunt is also more severe in the Western portion.[32] Of 26 samples from the terminal market at Minneapolis, Minn., 23 were from Montana, 2 from North Dakota and 1 from Minnesota.

Appearance in the field.—Although the wheat plant is infected only while it is a very young seedling, either before it appears or as it appears above the ground, no signs of the disease are visible until about the time the head begins to fill. The smutted heads are a darker green and remain green longer than the normal heads. In varieties, where the normal heads bend over slightly under the increasing weight of the grain, the affected heads stand invariably more erect. In the Club varieties the normally compact head is changed to a more slender

[30] U.S.D.A. Plant Disease Reporter Supplement 35:250. 1924.
[31] Stephens, D. E. and H. M. Woolman. Oregon Agr. College Exp. Sta. Bul. 188. 1922.
[32] Morris, H. E. and A. J. Ogaard. Mont. State College, Ext. Service Bul. 74. 1925.

type. In the awned varieties, the awn is usually more brittle and breaks off readily leaving the bunted heads almost bald. The infected heads of almost any variety have a more loose or open appearance due to the more marked divergence of the glumes. This is caused by the greater plumpness of the developing bunt-balls than of the healthy grain, and by the setting of more rows of bunt-balls in the diseased heads than of grains in normal heads. In some varieties the bunt-balls become very noticeable, in others they are detected with difficulty.

A plant may be wholly or partially smutted. Sometimes all the heads of a plant, at other times only one or two, may be affected. Besides, the heads themselves may be partially smutted, both normal grains and bunt-balls occurring together in the same head. A careful examination of a number of partially smutted heads showed that the smut-balls and the kernels were not distributed irregularly in the heads, but that the bunt-balls stood by themselves, one above the other. One side or one edge of the head was infected while the rest of the head contained healthy kernels. Not all heads were smutted to the same extent. All gradations from almost perfectly sound heads to almost completely smutted ones existed, but this arrangement just noted remained unaffected. Moreover, between the healthy portion and the smutted part of a head kernels partially smutted occurred, thus forming a kind of transitional zone.

Partial smutting may be explained as follows: Each head of wheat is produced in a separate shoot with a definite and individual growing point. Generally speaking, the fungus attacks the various growing points at an early age, but when, for some reason or other, the first heads have escaped infection, a second growth may not succeed in making its escape, and, the growing points being invaded by the fungus will carry the infection until ultimately infected heads are produced. Besides, in some cases, the fungus seems to be confined to a part of the growing region of the head, so that a strand of infected tissue is formed back of the growing point, resulting in a smutted strip along one side. In this way it would be reasonable to expect occasionally that sound and unsound heads may be produced by one plant, and that sound, partly diseased, and wholly diseased grains may occur in the same head.

If a well-matured bunt-ball is squeezed between the finger and thumb it will burst open smearing the fingers with a greasy or dusty powder. This substance is composed entirely of spores of the bunt fungus and smells strongly of herring brine. The bunt-balls do not normally break open in the field and the infected heads are harvested with the sound ones.

The fungus spores.—When such wheat is subsequently threshed, a large number of the smut-balls are broken, and the spores thus set free will infect the sound wheat grains. When badly infected wheat is being threshed, the spores are present in such large numbers that one may often notice a black cloud issuing from the threshing-machine. It is not generally realized that there may be from two to three millions of spores in each smut-ball. To comprehend the size of the spores and enable one to realize the extreme danger of sound grain becoming infected, a photograph has been taken of smut spores among which a human hair has been placed for comparison. This photograph shows the spores, as well as the hair, much enlarged, but both to the same extent, and we can now measure for ourselves that eight smut spores may be placed side by side in order to stretch across a hair (fig. 1; a). Once this minuteness of the single spore is comprehended, it will not be difficult to realize the extreme caution necessary to prevent them from flying about and settling upon farm machinery, implements, tools, manure heaps, etc., from which they will be ultimately conveyed to the soil. In addition, there is the danger that direct infection of the soil may take place under the conditions already discussed in

FIG. 3.—Bunt and loose smut of wheat. (*a*) A sound head, lower half with chaff removed showing the sound grains in place. (*b*) Head infected with bunt showing the characteristic spread-out appearance; note the four smut-balls showing where sound grains would have been formed. (*c*) Head partly affected with bunt; the cross indicates a perfectly sound wheat grain. Below this all grains are more or less completely infected with bunt. (*d, d*) Two heads of wheat destroyed by loose smut, picked at the time of flowering; no grains are formed. All figures slightly above natural size.

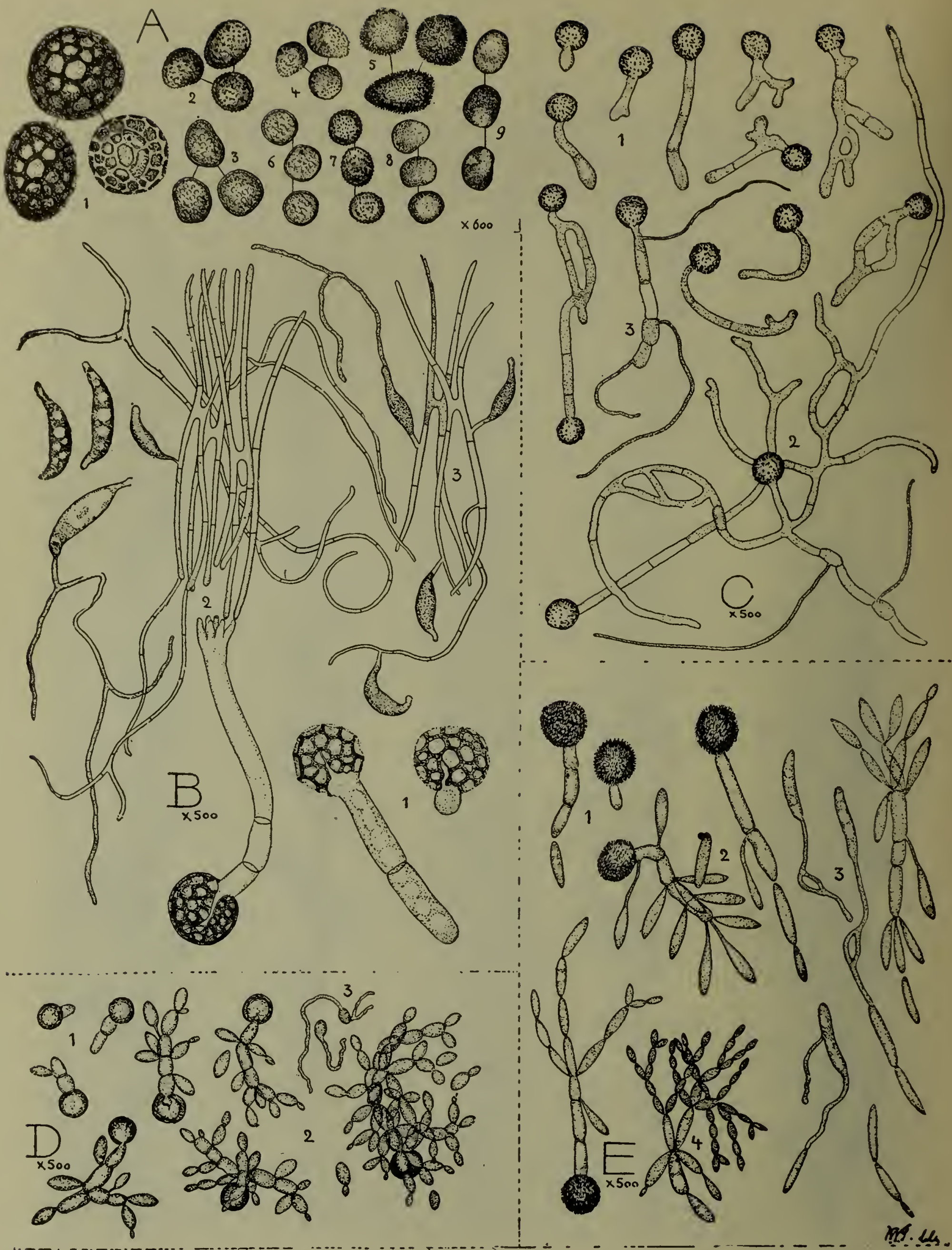

FIG. 4.—A. Three spores of each of the following kinds of smut. (1) bunt or stinking smut of wheat; (2) naked-smut of oats; (3) smut of fox-tail millet; (4) loose smut of wheat; (5) corn smut; (6) covered kernel smut of sorghum; (7) loose smut of barley; (8) covered smut of barley; (9) covered smut of oats. B. Germination of bunt spores. (1) early stages showing bursting of the spore wall and the growth of the promycelium or basidium; (2) stout basidium terminating in a crown of points from which a wreath of slender rod-shaped primary conidia are produced, some of which are shown germinating; (3) primary conidia producing basidiospores, one of which has germinated. C. Germination of loose smut spores of wheat. (1) early stages; (2) a spore observed in artificial culture for 12 days; (3) the promycelium producing thin germ-tubes. D. Naked smut spores of oats germinating. (1) early stages; (2) showing masses of secondary spores; (3) two secondary spores producing thin germ-tubes. E. Corn smut spores germinating. (1) early stages; (2) production of secondary spores; (3) secondary spores germinating; (4) production of air conidia from secondary conidia.

the introductory chapters. Each individual spore is capable of spreading the disease.

We have already compared the fungus spore to the seed of plants. Just as the seed or kernel of wheat is the agent reproducing the wheat plant, so is the fungus spore the " seed " of the smut disease.

The spores of the stinking smut fungus are minute, round, brownish bodies, with a smooth or reticulated surface, according to the species.

Longevity of spores.—The longevity of wheat bunt spores has been repeatedly investigated. The free spores may remain viable for at least three years, but spores from unbroken smut-balls kept in a dry condition were capable of germinating after a period of twelve years. Wheat that has been kept for eight years under suitable conditions of storage, and which at first germinated 99 per cent., showed only a germination of some 47 per cent. This makes it practically useless to store infected wheat in the hope of securing freedom from smut. The longevity of stinking smut spores is of importance to the fungus itself as it is a natural adaptation to the conditions under which the fungus plant has to live. Should the spores remain alive for a short time only—as is the case with the true loose smuts—then the possibility of the smut perpetuating itself would be very limited. The function of the seed or the spore is to reproduce its kind, hence plants depending entirely upon this mode of reproduction have generally long-lived seed.

The germination of the spore.—When wheat contaminated with smut spores is sown, the spores pass through various stages of development before the wheat plant becomes infected. At first, the outside wall of the smut spore bursts open and a short, stout germinal tube is pushed out (fig. 4; B, 1). This was formerly known as the promycelium. Recent researches of Buller and Vanterpool[33] have shown that it should be regarded as a true basidium. The next stage is the production of a series of slender rod-shaped primary conidia arranged around the apex of the basidium (fig. 4; B, 2). These conidia unite in pairs, each pair forming an H-shaped structure. The basidiospores proper are produced on short stems either directly on this structure or on a fine hair-like mycelium which develops from it (fig. 4; B, 3). The basidiospores in turn may put forth fine hair-like tubes. These are the infection tubes. When they come in contact with the germinating seed, from the moment the rootlet is formed to the time the first leaf is ready to push through its protective sheath, infection is almost sure to result. The infection tube pierces the young and tender tissues of the wheat seedling, and when successful in reaching the growing point, it continues to grow with the plant, giving no indication of its presence until spore production takes place in the head. (Fig. 2).

Stinking smut confined to wheat.—Microscopically and biologically, stinking smut of wheat is quite different from other grain smuts. Each kind of grain has certain parasites peculiar to itself which cannot affect any other plant. For instance, when barley or oat seed is contaminated with wheat bunt spores and sown, no infection from the bunt will take place; similarly, oat smut spores do not infect wheat or barley. Besides, each smut being distinct, the method of infection is not always the same. This has been discussed in Part I. For these reasons the treatment for the control of one smut is frequently not satisfactory for that of another. Sometimes differences in varieties of the same cereal make it necessary to use different treatments for the same smut. Copper carbonate is most satisfactory for control of smut in hulless oats, while formalin gives good results with the common hulled varieties, but invariably proves injurious to the " naked " varieties.

[33] Buller, A. H. R. and T. C. Vanterpool. Nature 116:934-935. 1925.

SEED TREATMENTS FOR THE CONTROL OF BUNT

Advisability of treating all wheat before sowing.—When wheat is obviously bunted the seed must be treated before sowing to ensure a clean crop. In such cases, the bunt spores are present in considerable quantity and their presence is readily detected by the odour and by the blackening of the brush. Bunt spores, however, may be present on seed in considerable numbers and still not be easily detected either by appearance or odour. When such seed is sown, without first being treated, the resulting crop may be seriously bunted if the conditions at seeding are favourable for bunt infection. Moreover, seed which is free from bunt may become contaminated from a dirty thresher, smutty bags, or other sources. This slight infection may subsequently increase to destructive proportions. As a light infection is very difficult to detect and is most apt to be passed over, it is advisable to treat all seed before sowing in order to prevent on outbreak of bunt.

This recommendation to treat all seed is equally important for the control of other smuts, which, like wheat bunt, infect the seedlings. But field observations have shown that these smuts, particularly those on oats, are more prevalent than wheat bunt. As they are readily controlled by seed treatment it is evident that seed grain other than wheat is not as regularly treated before sowing as it should be.

It has been stated that no ill effects may be noticed from the smut fungus growing within the plant until the heads appear, when they are found to be destroyed. Sometimes, however, the fungus is feebly present within the plant and may not succeed in reaching the heads. The heads will, therefore, escape infection, but the grain will be of poorer quality.

For this reason it is desirable to use seed from a crop which is known to have been free from any smut infection. Wherever possible, only plump well-developed grain should be sown, as it will produce the best plants and highest yields, whereas imperfectly developed grain will be of low vitality and will ordinarily produce an inferior crop.

Importance of controlling smut in élite-stock, and registered seed.—The Canadian Seed Growers' Association has accomplished an important work in producing excellent strains of the leading varieties of cereals and in maintaining the purity of the strains after they have once been produced. The result is that Canadian seed is recognized to-day as being of a very high quality and purity. But, besides possessing purity of variety and freedom from noxious weeds, etc., all élite-stock and registered seed should be free from disease. This freedom from disease may be an ideal that cannot always be attained, but with the smut diseases which are well understood and for which the means of control are known, no difficulty should be experienced in keeping the seed relatively free from contamination.

The first thing required is that a clearly defined standard of freedom from smut be established. This standard must necessarily be set quite high, because, when a grower purchases seed and finds any trace of smut in the crop grown from that seed, he is naturally disappointed and his incentive to buy high-quality seed is undermined. As a result of the work already done by the Canadian Seed Growers' Association, it would seem undesirable to issue a certificate for a crop showing more than one-tenth of 1 per cent of smut. Under the present method of estimating the purity and freedom from disease, six counts are made in each field, care being taken to obtain these counts from points well separated from each other. Each count covers an area of 15 paces long and 20 feet wide. This area is approximately one-fiftieth of an acre, and contains on the average 10,000 plants of small grains. Consequently, if more

than an average of 10 smutted plants, or a total of 60 plants, are found in the six counts, the crop should be considered ineligible for registration.

This standard may be considered very high, but, if more smut is permitted, it is very readily noticed, and the public is prejudiced against the value of high-quality seed. Whether the true loose smuts or the more easily-controlled covered smuts be present, the standard permitting not more than one-tenth of 1 per cent of smut seems highly desirable. In the first place this standard can be readily attained in the case of the easily-controlled smuts, as wheat bunt, covered smut of barley, and the smuts of oats. If a larger percentage of smut occurs, it indicates that the grower neglected to treat his grain, or did not understand the requirements of the treatment. In the second place, the difficulty of treating seed for the loose smuts of wheat or barley makes seed free from these diseases exceedingly desirable. Unless a high and definite standard is maintained the purchaser of seed grain is not protected against an outbreak of loose smut in his crop.

Seed lots of varieties known to be susceptible to loose smut should be rejected, if, at the time of field inspection, the crop be found to contain more than one-tenth of 1 per cent of smut. In varieties, however, which, due to inherent resistance, usually show a percentage of smut lower than the standard, a slightly higher percentage might occasionally be permitted.

A standard permitting only one-tenth of 1 per cent of the easily controlled smuts may be considered too high, as the presence of these smuts does not otherwise affect the quality of the seed, and they may be removed by proper seed treatment the following year. In this connection it may be pointed out that valuable seed stocks need not be lost by being rejected on account of smut, while a high standard is maintained. When the amount of an easily controlled smut in a crop exceeds the standard, but the crop is satisfactory in other respects, permission to increase the seed might be given on the understanding, that it would be treated to eliminate the smut before sowing the next year Only that portion of the seed held by the original grower would come under this provision, the remainder, if any, would have to be disposed of under the regular market grades. If this seed produced a crop free from smut and eligible in other respects, a regular certificate would be issued on the new seed.

Whether this suggestion is adopted or not, it is fully evident that the recommendation of the previous section applies with equal force in this case. It is not only important that the average grower treat all his seed before sowing, but that the grower of élite-stock or registered seed should take even greater precaution.

Cleaning the seed previous to treatment.—All wheat or other grains should be thoroughly cleaned before treatment, no matter what the treatment employed may be. There are several reasons why this should be done. In the first place, all grain must be cleaned before it is fit to sow, for only in this way can weed seeds, chaff, broken kernels, and dirt be removed. Besides being a good agronomic practice to follow, there are additional reasons for cleaning seed which has to be treated. Unless grain is cleaned before treatment the efficiency of the treatment becomes seriously impaired, as will be shown in the following paragraphs.

If a dust treatment is applied the particles of chaff and dirt adhering to the seed prevent the dust from adhering properly to the grain, because seed can only carry on its surface so many particles whether they be of inert matter or those of the chemical dust. The particles of dust which do not adhere to the seed play no part in controlling the smut. As dust-treated grain cannot be fed to stock, any screenings removed from the grain after it is treated are worthless. Besides, the dust which adheres to the screenings is also wasted.

Moreover, the usual fanning-machine could not be used to clean dusted seed, for the operator would be made sick by inhaling the heavily dust-laden air.

If a wet treatment is employed, the impurities as well as the seed use up the solution, and hence, in the treating of uncleaned seed, the part used up by the impurities is a direct loss. Besides, a thorough wetting of the seed by the solution is essential for good results from the treatment. The fact that clean seed is more easily wet than dirty seed by the solution adds another argument for cleaning the seed.

In the case of bunt, there are additional reasons for employing clean seed. During the process of cleaning, the bunt-balls are nearly all blown out of the grain. This removal is very important, particularly if a wet treatment is to be used, for no solution will penetrate the unbroken bunt-balls, and consequently, unless they are removed, some of them are likely to be broken open or crushed, thus permitting a reinfection of the grain and rendering the treatment of little value. Where the dust treatments are used, the danger of reinfection from broken bunt-balls is guarded against by the presence of the dust on the seed, but, as pointed out, unless the grain is cleaned, the cost of the treatment is increased and its efficiency is lessened.

Treatments recommended.—The ideal seed treatment is one which satisfactorily controls smut without injuring the germination of the seed and which, at the same time, is neither too laborious nor too costly. A treatment which fails to meet all of these requirements is not satisfactory from the practical standpoint, even though it effectively controls the disease. In many instances the choice between two or more equally effective treatments will depend on the availability and cost of the chemicals, and the extent to which the seed is smutted.

For the control of wheat bunt, copper carbonate dust has given very satisfactory results and is therefore recommended. When it is properly applied it gives good control, while it does not injure the seed in the least. Dusting may be done months before the busy spring season begins without danger to the seed or fear of its subsequent contamination. Although copper carbonate is at present more expensive than formalin, the saving of seed and the more uniform stand should compensate for the increased cost.

Formalin has been used more extensively than any other fungicide on account of its efficiency in eliminating smut, but, in common with copper sulphate (bluestone), it causes more or less injury to the seed, no matter how carefully it is applied. For these reasons formalin is only recommended when the seed is exceedingly smutty. Copper carbonate will reduce but cannot control bunt, when the spores not only blacken the brush but also collect in visible specks over the surface of the seed. However, only the exceptional sample is smutted to that extent.

If copper carbonate dust is not used, the formalin sprinkle treatment is recommended as next best, because of the ease and simplicity of applying it. In addition to this there are several other methods of using formalin for the control of bunt which also give satisfactory results. The commonest of these is by immersing the seed in formalin solution, either in bulk or in bags. Various pickling-machines are also on the market and many of these treat the grain satisfactorily. However, none of these other treatments with formalin are any better than the formalin sprinkle, except in very special cases which will be noted in the discussion of the respective treatments.

COPPER CARBONATE DUST TREATMENT

Copper carbonate dust is an amorphous greenish powder and is entirely free from crystals, when pure. Chemically it is a basic copper carbonate containing one part of copper carbonate combined with one part of copper hydrate. The proportions of copper carbonate and copper hydrate vary somewhat widely; the copper hydrate increases at the expense of the copper carbonate, if too high a temperature is maintained during manufacture. Copper carbonate is insoluble in water, but it is slowly soluble in weak acids, such as carbonic acid. Doubtless organic acids in the soil render it sufficiently soluble to prevent the germination of the spores. Copper carbonate of good quality is very stable under ordinary conditions and is not subject to deliquescence or crystallization. If stored in a dry place the dust will keep almost indefinitely.

Copper carbonate dust was first tried in New South Wales for the control of bunt. Darnell-Smith,[34] in 1917, reported better results with copper carbonate than with bluestone solution followed by lime, the standard treatment in Australia. Since that time it has been tested in the United States, South Africa, England and other European countries, and it is now used extensively in Australia and the United States. In the Pacific Coast States where infection from spores in the soil is a serious problem and the germination of the seed is greatly reduced by formalin, the treatment has rapidly displaced the older treatments. In California it was estimated that, in the fall of 1922, 250,000 acres were sown with seed dusted with cooper carbonate. In other important wheat-growing States, as Kansas, Minnesota, North Dakota, Montana, etc., it is now recommended for the control of wheat bunt. In Western Canada copper carbonate has been tested extensively for a number of years for the control of wheat bunt by the Division of Botany. Bunt has been as well controlled with copper carbonate as with formalin and with no injury to the seed.

Advantages of the copper carbonate treatment.—Treating seed grain with copper carbonate dust possesses some notable advantages over formalin. As has been mentioned already, copper carbonate does not injure the germination of the seed as formalin does. When a formalin solution is strong enough to destroy the smut spores on the seed, the germination of the seed is injured. In table 6 are given the result of one test. The results are typical of the effect that these fungicides have on germination.

TABLE 6.—EFFECT OF SEED TREATMENT ON THE GERMINATION OF MARQUIS WHEAT IN SOIL IN THE GREENHOUSE

Treatment	Percentage of germination		
	Strong	Weak	Total
Formalin	84	6	90
Copper carbonate	96	2	98
Check-Untreated	94	4	98

The modern high-speed thresher causes many kernels to be cracked or broken. Breaks in the seed-coat, especially over the embryo, permit increased injury from formalin. The amount of injury is also increased when seed is sown in a dry seed-bed. Moreover, there is always some risk in using wet treatments. The grain must be dried if it cannot be sown immediately, and there is danger in the meantime from frost, or from heating, or sprouting.

[34] Darnell-Smith, G. P. Agr. Gaz. New South Wales 28:185-189. 1917.

Besides, adjustment of the seed-drill must be made to accommodate the swollen grain. On the other hand, seed may be treated with copper carbonate at any time during the year and stored without fear of injury, for germination is not affected in any way.

The principle of dust treatments.—For the control of wheat bunt with copper carbonate, the surface of the grain must be covered with an *even film of dust.* Such a film can only be obtained when a machine-duster is used to apply the dust. In our experimental trials with copper carbonate the dust was applied to the seed by shaking the seed with the required amount of dust in a small container and also by using a small machine-duster. In every case, bunt was more completely eliminated when the dust was applied by machine than when the dust and seed were shaken together. Merely shovelling the grain and dust together will not give satisfactory results.

Selection of the dusting-machine.—The dusting-machine that a farmer should select for his use depends largely on the acreage that he sows to wheat. For large acreages, one of the large commercial machines is most desirable. One machine has already been placed on the market in Western Canada, and other makes will undoubtedly follow. A satisfactory duster might be made from a small concrete-mixer of the barrel type, if it is provided with a dust-tight lid. Both commercial dusters and concrete-mixers are sold in various sizes and may be operated by hand or by power. When power-driven, they may be operated in conjunction with the fanning-mill, the cleaning and dusting of the grain becoming one continuous operation. For small acreages one of the home-made mixers to be described will give satisfactory results.

Description of dusting-machines.—(a) Commercial machines.—A number of dusting-machines have been designed and placed on the market in the United States by commercial firms. Of the different designs that have been brought out, those machines which are built on the principle of the barrel mixer (fig 6), to be described, are very popular. The copper carbonate dust and wheat are fed into a dust-proof cylinder through separate hoppers at one end and the subsequently thoroughly dusted grain is discharged at the other. The dust may be applied to the seed at any rate desired. As the operation of a commercial machine is continuous, large quantities of grain may be treated in a relatively short time. To obtain the best results with such a machine, the directions for operating should be carefully followed. The copper carbonate feed should also be regulated carefully to deliver the required amount of dust.

(b) Concrete-mixer.—A concrete-mixer of the simple barrel type operated by hand or by gasoline engine is sometimes part of the farm equipment. Where it is available it will make an excellent duster, provided it is clean and smooth inside and is furnished with a suitable cover over the mouth of the barrel to hold in the dust while the wheat is being treated. This mixer works satisfactorily if the charge is one bushel. Fifteen to twenty revolutions will give a thorough mix.

(c) Churn treating-machine.—A mixer of small capacity can be readily made from a barrel churn of 20-gallon capacity or larger. This may be used as it is, or it may be made more efficient by inserting mixing blades of galvanized iron (fig. 5). Melchers and Walker[35] have fully described and illustrated the making and fitting of the mixing-blades to the churn. Their description is as follows:—

"The patterns for cutting and bending the blades are indicated in the figure. The lower mixing-blade is placed near the bottom at angle of 45° with the floor of the churn. The centre blade has a width equal to half the largest diameter of the churn, but it is placed in the centre with both sides open, and with the plane of the blade at right angles to the plane of the lower blade. The upper blade is placed near the head of the churn, forming an angle of 45° with the top and parallel to the lower blade. It is similar to the lower blade with exception of an opening next the staves to facilitate the draining of the wheat after the charge is sufficiently mixed. Large carpet tacks, or small screws, may be used to fasten the blades in place.

"The position of the blades is such that when the churn is revolved as indicated by the arrow in fig. 5, the copper carbonate and the grain are thoroughly mixed together.

[35] Melchers, L. E. and H. B. Walker. Kans. Agr. Exp. Sta. Circ. 107. 1924.

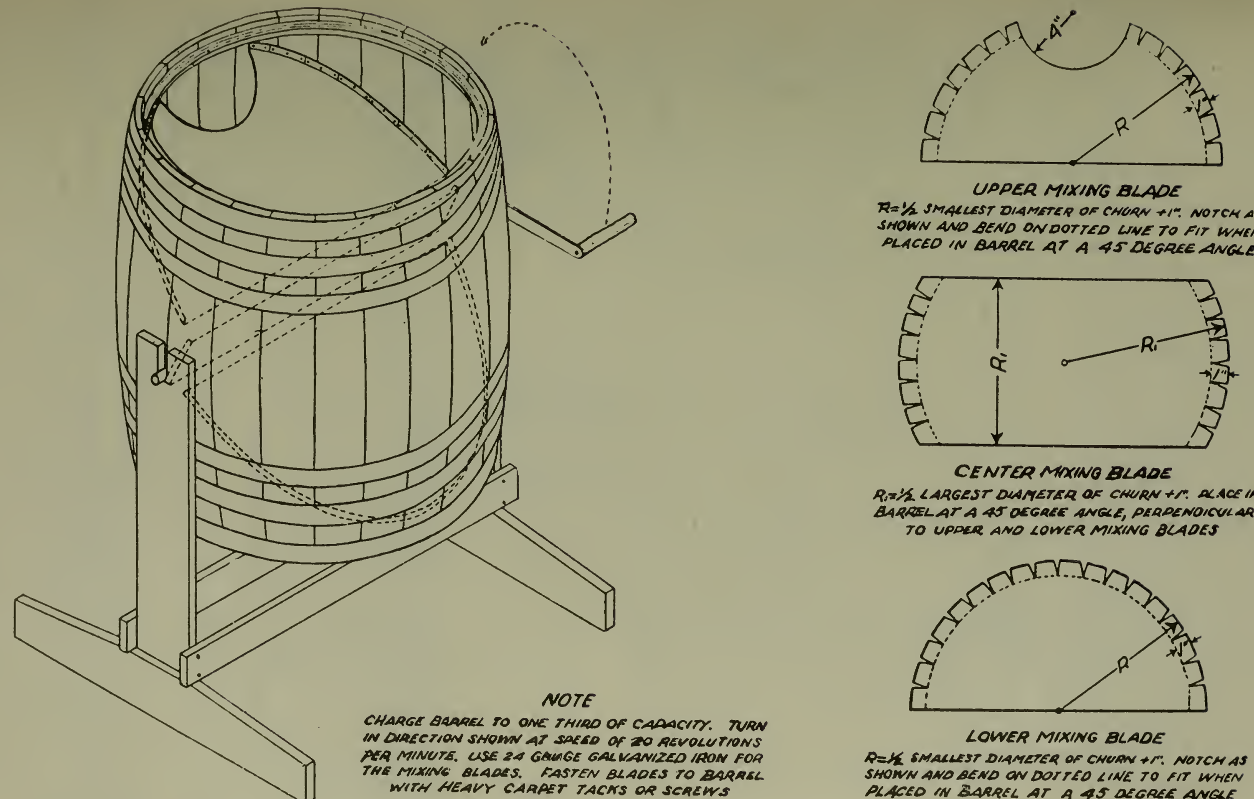

FIG. 5.—Plans for a churn smut-treating machine. (After Melchers and Walker, Kans. Agr. Exp. Sta. Circ. 107. 1924.)

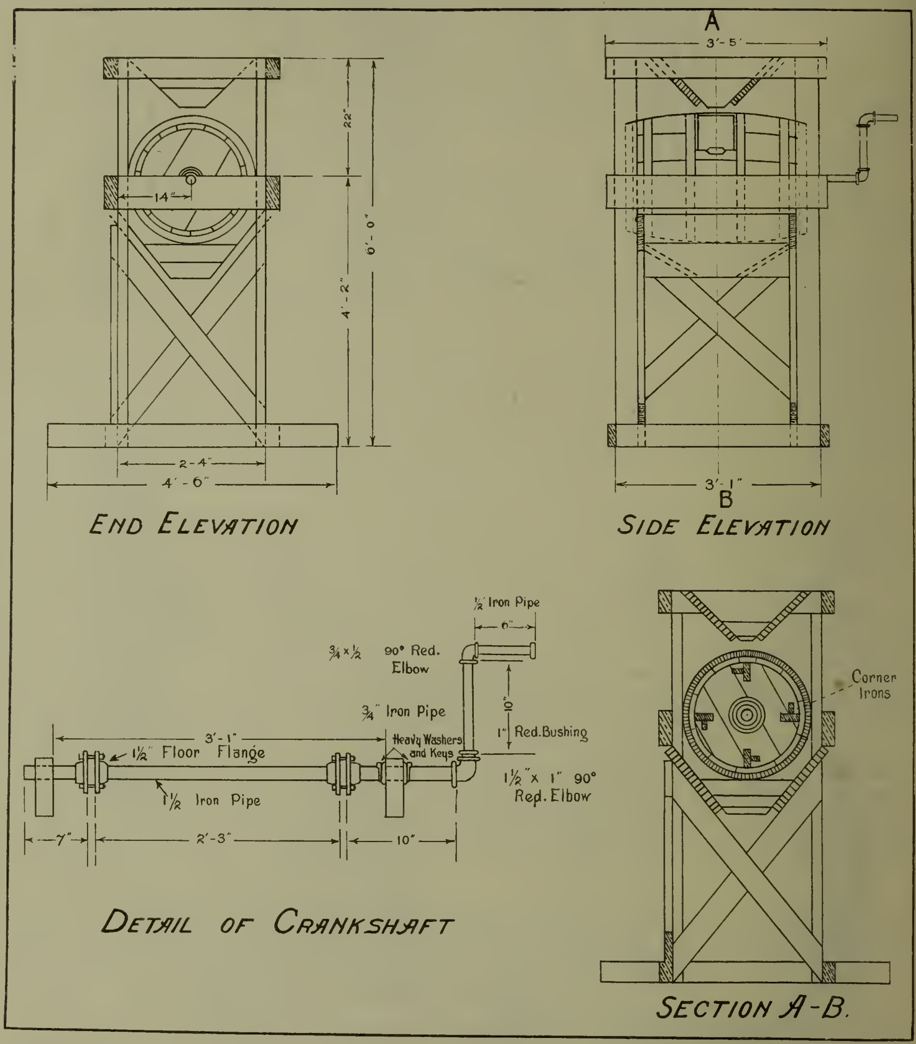

FIG. 6.—Plans for barrel smut-treating machine. (Adapted from Melchers and Walker, Kans. Agr. Exp. Sta. Circ. 107, 1924.)

The proper charge for this type of mixer is three pecks, and the churn should be operated at the rate of approximately 20 revolutions per minute. Thorough mixing requires at least 1½ minutes."

If the churn is used without the blades, 3 minutes will be required to mix the grain thoroughly.

(d) Barrel treating-machine.—One of the most satisfactory home-made mixers of the cylinder type is made from a barrel. Melchers and Walker[35] have listed the materials required for such a mixer and have given full directions for building. Their account will be followed almost throughout in the following description. In fig. 6 the plan of construction is shown. This plan may be modified somewhat if all the materials suggested are not available. If the mixer is equipped with upper and lower grain-hoppers as illustrated, the grain may be treated easily and rapidly. The mixer has a charge capacity of one bushel. For thorough mixing, the barrel should be revolved at a rate of 30 revolutions per minute for 1½ minutes. The cost of material for construction is about $15.

The following materials may be purchased locally if not already available on the farm:—

Bill of Materials for Barrel-treating Machine

No.	Size	Length	Grade	Item
1.....	2" x 6"	12'	No. 1 dimension....	Framing.
3.....	2" x 4"	12'	"	"
1.....	2" x 4"	16'	"	"
1.....	1" x 10"	12'	No. 1 shiplap.......	Hoppers.
1.....	1" x 8"	12'	"	"
2.....	1" x 4"	12'	No. 1 boards........	Mixing-blades or braces.
1.....	1" x 4"	14'	"	"
1.....	1½"	2' 3"	....	Iron pipe.
1.....	1½"	10"	....	"
1.....	1½"	7"	....	"
1.....	¾"	10"	....	"
1.....	½"	6"	....	"
1.....	1½" x 1"	....	....	90° reducing elbow.
1.....	¾" x ½"	....	....	"
1.....	1"	....	....	Reducing bushing.
1.....	½"	....	....	Cap.
4.....	1½"	....	....	Floor flanges.
8.....	¼"	2"	....	Stove bolts.
2.....	2"	....	....	Pipe lock nuts, or heavy washers and keys.
32.....	....	1"	....	Wood screws.
2 lb..	....	3½"	Wire.................	Nails.
1 lb..	....	2½"	"	"
1.....	....	....	Standard...........	Vinegar barrel.

"Cut the four corner posts, each 6' long, from two of the 2" x 4" x 12' material. Cut two top end framing pieces each 2' 4" long and two top side framing pieces each 3' 5" long from the 2" x 4" x 12' material. Nail side framing to end framing, forming a rectangle with inside dimensions 2" x 4" wide by 3' 1" long. Use 3½" nails. Square the corners carefully.

"Cut two lower end framing pieces each 4' 6" long and two lower side framing pieces each 3' 1" long, from the 2" x 4" x 16' material. Nail the end framing to the side framing to form a rectangle with inside dimensions 2' 4" wide by 3' 1" long. Note that the end framing pieces project beyond side framing to form base support. Square the corners carefully and nail, using 3½" nails.

"Place the 2" x 4" x 6' posts in position between the rectangles with the 4" dimensions along the side of the frame and the 2" dimension along the end, as shown by figure 6, and nail securely to upper and lower frames using 3½" nails.

"Cut two intermediate side framing pieces each 3' 5" long and two intermediate end framing pieces each 2' 4" long from the 2" x 6" x 12' material. Bore a 2" hole, centered 14" from the end and 1" from the top side, through each of the two end framing pieces to form the bearing for the crank-shaft. Nail these two intermediate pieces to the corner posts with upper side 22" from the top of the posts as shown by the plan (fig. 6). Use 3½" nails.

"Cut two diagonal end braces from one end of the 1" x 4" x 12' boards and one diagonal end brace from the remaining 1" x 4" x 12' board. The fourth diagonal end brace is cut from the 1" x 4" x 14' board. Square the frame carefully and nail the end braces to the inside of end posts using 2½" nails. Note that the end braces must be high enough on the posts that the shiplap, when placed in position, will have its upper edge flush with the lower inside edge of the 2" x 6" intermediate side framing pieces.

"Cut the two diagonal side framing pieces from the remaining part of the 1″ x 4″ x 14′ board. Square framing carefully and nail securely in place on outside posts as shown on the plan. Use 2½″ nails. Now cut two pieces from the 1″ x 10″ x 12′ shiplap and two pieces from the 1″ x 8″ x 12′ shiplap to fit between the side posts to form the sides of the lower grain-hopper. Place one 1″ x 10″ and one 1″ x 8″ piece on each side and nail these securely to end braces with 2½″ nails. With the sides of the hopper now formed, the ends may be built from the 1″ x 10″ and the 1″ x 8″ shiplap. Cut these to fit when placed to slope downward at an angle of about 30° to centre. Use 2½″ nails.

"Bore a 2″ hole through the centre of the top and bottom barrel heads. Remove one head from the barrel being careful to avoid breaking the boards since this head must be replaced after the mixing-blades and crank-shaft are in position. Cut an opening inside of barrel at centre selecting a combination of two staves which will give the largest opening without cutting any staves entirely in two. Make the opening approximately square. The ends of the opening should be about ⅝″ from the centre barrel hoops.

To form a covering for the barrel opening cut two strips of galvanized iron about 1¼″ wide and 1″ longer than the opening. Bend the strips at right angles along their length and fasten with suitable screws to the outside of the barrel along the opening. Cut another strip 1¼″ wide with a length equal to the distance between the adjacent barrel-hoops and bend as above. Attach to barrel by means of suitable screws at top of opening, placing this strip under the ends of the two side strips.

"Cut a galvanized iron lid to fit between the upturned edges of side strips and make this about 3″ longer than the opening. Place this over the opening and with hammer or mallet bend the side strips over the cover. Then bend the end strip over the end of the side strips and over the cover. These side strips and end strips now form a guide for the door, the lower end of which may be bent to form a handle for opening and closing.

"Cut four mixing-blades each 2′ 3″ long from the remainder of the 1″ x 4″ boards. Shape roughly to the curve of the barrel. Fasten the corner irons to the mixing-boards, with suitable screws, in such a manner that the lower irons screw fast to the bottom head of the barrel and the upper irons to the staves of the barrel. Space these equidistant around the inside of the barrel."

The crank-shaft (fig. 6) is in three sections, a central one within the barrel and two end sections, to one of which the handle is attached. Be careful to see that the length of the pipe of the central section is just the distance inside between the bottom and top heads of the barrel. On the outside of the top and bottom heads mark the places where the bolts holding the floor flanges are to go through. One of the floor flanges may be used as a pattern. Bore out these holes. Now stand the barrel on two supports so that its bottom head will be raised about one foot above the ground to permit the assembling of the crank-shaft. Stand the central section of the crank-shaft in place so that the holes in both the flange and bottom head coincide. Insert the bolts. Bring the short end section of the shaft into place and bolt the two flanges securely together. Now replace the head. Similarly bolt the flanges at the top head together. The barrel may now be replaced in the frame. The lock nuts or the heavy washers and keys should be set before treating is started to prevent the crank-shaft working sideways in its bearings.

"The upper grain-hopper may now be built from the 1″ x 8″ and 1″ x 10″ shiplap. This hopper is 10″ square at the top, 6″ square at the bottom and 9″ deep. The sides slope to the centre at an angle of approximately 45°. The dimensions given are approximate outside dimensions. The boards making up this hopper must be carefully sawed and fitted. Use 2½″ nails.

"The hopper must be so placed that it will centre directly over the outside door to the barrel when the door is removed for filling. Note that the ends of the upper side pieces of the hopper are left square in order that they may support the hopper in the 1″ x 2″ cleats, which are nailed to the sides of the main frame as indicated in the plan.

"The tools required for the construction of this smut-treating equipment are: Claw hammer, hand cross-cut saw, key-hole saw, square, pipe-wrench, tinner's snips, brace and bits."

*(e) Box Treating-Machine.**—A cheap and very efficient mixer may be made from a dust-proof box of stout construction. If one is not already available a box 2′ x 2′ x 2′ is a very convenient size (fig. 7). Thorough mixing is most easily attained by mounting the box diagonally. For a box of these dimensions, the following materials are required for the axle and crank: 1 piece of 1¼″ pipe 6′ long, threaded at one end; 1 piece of 1″ pipe 10″ long, threaded at both ends; and 1 piece of 1″ pipe 8″ long, threaded at one end; one 90° reducing below 1½″ by 1″, and one 90° 1″ elbow. Instead of making the crank from piping, a crank that had been discarded might be riveted to the axle.

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* Prof. G. L. Shanks, Head of the Department of Agricultural Engineering, Man. Agricultural College, Winnipeg, Man., made many helpful criticisms and suggestions on the construction of the different dusting-machines described, for which we express our thanks.

The axle is supported on a pair of substantial saw-horses. They should stand 32″ from the floor, a convenient height for turning the machine. Bearings for the shaft may be made from a hardwood block 2″ x 4″ x 8″. Bore a hole 1½″ in diameter in the centre of the 4″ face. Saw the block lengthwise into halves so that each piece is 2″ x 2″ x 8″ and each has a half round bearing surface across its face for the axle. Bolt these blocks to the saw-horses. Two 2″ iron washers are placed on the axle at the crank end to keep it from sliding in the bearings. The washers fit against either side of the bearing block and are held in place by cotter pins passing through holes drilled in the axle.

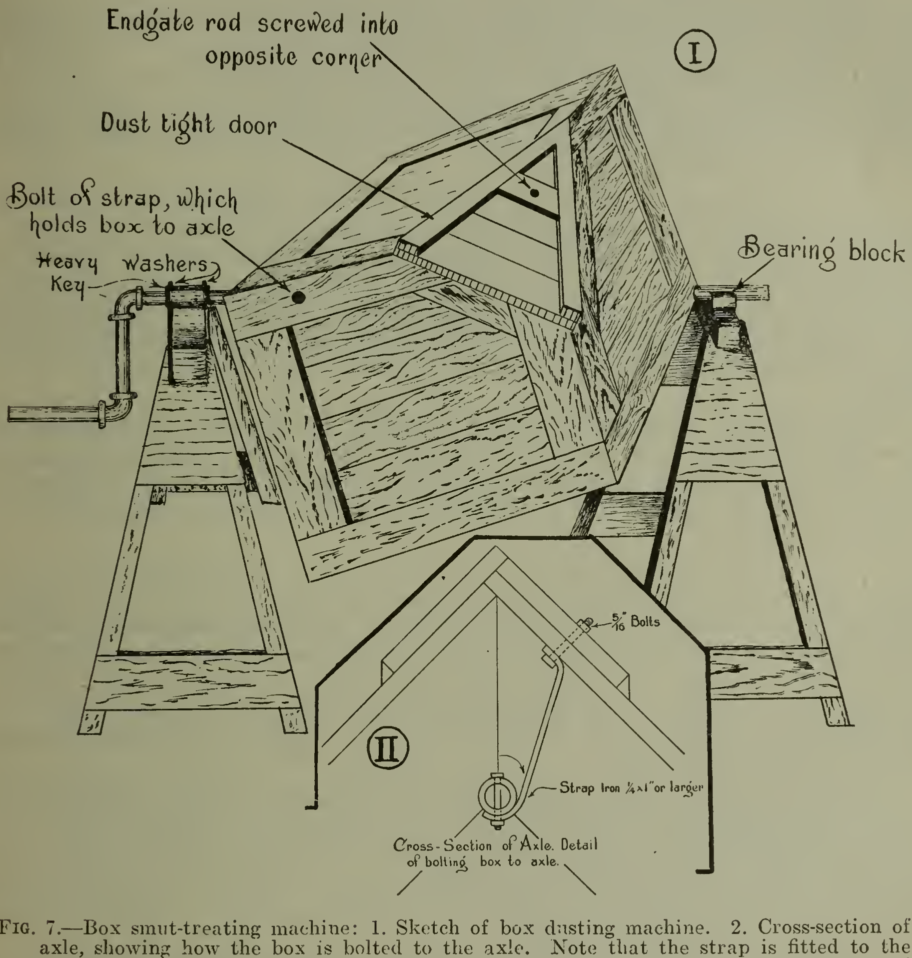

Fig. 7.—Box smut-treating machine: 1. Sketch of box dusting machine. 2. Cross-section of axle, showing how the box is bolted to the axle. Note that the strap is fitted to the axle so that when the axle is rotated, the strap pulls the box around. Direction of rotation is marked by an arrow.

An opening into the box is made by cutting away about 9″ from one of the free corners. A dust-tight door is made to cover the opening. The door is held in place by an end-gate rod screwed into the opposite corner. The rod should come through the door about 3″ off centre. To charge or empty the box the rod is loosened and the door rotated out of the way. When the door is swung into place and the rod screwed down the dust will be prevented from escaping.

The box is securely bolted to the axle in the manner shown in the detailed sketch (fig. 7). Two pieces of ¼″ x 1″ strap iron are bent to the required shape and the necessary holes bored in straps, pipe and box. The straps should be lapped around the pipe and bolted with 5/16″ bolts in position as shown in the sketch. For convenience in assembling, the holes in the pipe should be about 6″ from where the pipe runs through the box. A box of this size will hold a charge of one bushel. A single treatment requires 30 revolutions per minute for 1½ minutes.

Amount and kind of copper carbonate to use.—For ordinary bunted wheat, 2 ounces of copper carbonate are required to treat 1 bushel. If more than this amount is used the powder will accumulate in the drill, cause undue wear of the gears, or even set like cement and break the shaft. The dust is easily measured with a tablespoon; a heaping tablespoon weighs approximately 1 ounce.

For dusting purposes, the copper carbonate should have a light, green, not blue, colour. It should be fine enough to pass a 200-mesh sieve and be entirely free of lumps. The dust is then about as fine as Portland cement. Of the many brands of copper carbonate on the market, some contain 50 or more per cent of copper while others have a copper content of about 20 per cent. In tests conducted by the Division of Botany in Western Canada, brands of both classes gave satisfactory control of wheat bunt.

Copper carbonate is preferably bought in the manufacturers' containers. The dust is usually put up in packages containing 5, 10, 25, or 100 pounds. Although a number of brands have been tested by the Division of Botany, it has been unable to test all that have been put on the market on account of their multiplicity. Since some of these brands may be inferior, the farmer should secure as much information as possible concerning the brands he intends to use. Wherever information can be given, the Division of Botany will be glad to supply it.

Some confusion has arisen over the difference between copper carbonate and copper sulphate (blue stone as it is commonly called). Copper carbonate is a greenish amorphous powder insoluble in water, while copper sulphate is usually sold in the form of coarse blue crystals which dissolve in water to form a clear blue solution.

Where copper carbonate may be purchased.—Copper carbonate for dusting purposes is now handled by a large number of wholesale drug and hardware firms, as well as by many distributors of insecticides and other fungicides. A farmer should be able to purchase copper carbonate through his local drug or hardware store. The local dealer may not have a supply of copper carbonate on hand, but he should be able to secure it readily through one of the wholesale houses with which he deals.

Since the success of the copper carbonate treatment depends on each kernel being covered with an even film of dust, it is very necessary that the grain and copper carbonate be thoroughly mixed together. With the ordinary home-made equipment the mixer should be turned at the rate of thirty revolutions a minute and not less than $1\frac{1}{2}$ minutes are required to treat a charge. Machines should be filled only to their rated capacity.

Any treated grain left over after seeding is finished should be destroyed. It must not be fed to live stock or poultry, on account of the poisonous nature of the copper carbonate.

Precautions.—Copper carbonate dust is a poison. In reasonable amounts it does not affect the eyes, but the dust quickly causes nausea when inhaled. The operator should wear a dust-mask or a wet handkerchief over his nose and mouth. Dust-masks or respirators similar to those used in some industries are satisfactory. The air is freed from dust by drawing it through a small sponge which is kept moistened, or through a filter paper. They are of light construction and are not disagreeable to wear.

FORMALIN TREATMENTS

Formalin is a colourless liquid and has a very penetrating odour. It is sold by the manufacturer or wholesale house to local hardware or drug stores either in small containers of different sizes, suited to the needs of individual farmers, or in large containers for sale in bulk.

Formalin has been used more extensively than any other fungicide for the control of bunt and it has fully merited its popularity. When it was first introduced into Western Canada in the late nineties, wheat bunt was very prevalent and caused enormous losses in certain years. By continued seed treatment with formalin and to some extent with bluestone, wheat bunt has practically disappeared in some of the better farmed parts of the country. Formalin, however, almost always causes some injury to the germination of the seed and, consequently, other substances, which are less injurious to the seed and yet easily applied, are likely to take its place.

Strength of formalin solution used.—In all treatments for the control of wheat bunt, the strength of the formalin solution is always the same, and wherever these treatments are recommended for the control of other smuts no change in strength is made unless otherwise noted. The solution is prepared by adding one pound of formalin to 40 gallons of water and stirring till the formalin and water are well mixed together. Since this quantity of liquid may be greater than is required for use in a single day, any desired amount may be prepared in the above proportions by adding 1 ounce of formalin to every 2½ gallons of water. For accurately measuring out the formalin a four- or eight-ounce graduate, such as that sold for photographic purposes at most drug stores, will be found both convenient and inexpensive.

Methods of application—(a) Sprinkle.—If a formalin treatment is used for the control of wheat bunt, the formalin sprinkle is the one recommended under ordinary circumstances because of its ease of application. When bunt-balls are present in considerable numbers, however, the wheat should be immersed in bulk.

The wheat to be treated is placed in a pile on a clean floor, and sprinkled with formalin solution from an ordinary sprinkling-can or by means of a broom. The grain is then shovelled over into another pile, the grain being mixed as thoroughly as possible to distribute the moisture. The grain is again sprinkled and shovelled over. This operation is repeated until the grain is uniformly moistened. Forty gallons of solution will treat from 40 to 50 bushels of grain, approximately one gallon to every bushel. A little practice will show what quantity of the solution may be added most advantageously at one time in order that the amount of shovelling may not be unduly great.

When the proper amount of formalin solution has been sprinkled on the grain the solution is all absorbed by the grain during the period it is covered and although the grain becomes swollen it will run freely through the grain-drill. The treated grain should then be covered up for four hours with clean sacks, or canvas, to allow the gas liberated from the solution to thoroughly penetrate the mass.

Excess of liquid should be avoided for otherwise the bottom of the pile becomes too wet and will not dry out sufficiently to sow unless it is spread out thinly and the liquid thus given a chance to evaporate. The treatment may be carried out in a wagon box. The grain is piled in one end and sprinkled, and then shovelled over into the other. The sprinkling and shovelling is then repeated as often as required; afterwards the grain is covered for four hours, as already indicated.

(b) Immersion in bulk.—The most thorough treatment for the control of excessive amounts of bunt in wheat is the complete immersion of the loose grain in the formalin solution. This is very laborious, however, and need only be used when bunt-balls are still present in considerable numbers after the seed has been cleaned.

A convenient outfit for applying this treatment consists of two half-barrel tubs fitted with rope handles (fig. 8). A hole is bored in each tub near the bottom and fitted with a plug. The holes are covered with wire screening in order to hold the grain back when the liquid is being drained off. One tub is raised above the floor level on a pair of saw-horses or other solid support.

FIG. 8.—Simple equipment for treating with formalin, when the seed is to be immersed in bulk.

When ready to treat, the upper tub is filled about one-half full with the standard formalin solution (1 oz. formalin to $2\frac{1}{2}$ gals. water) and about one bushel of grain is added and thoroughly stirred. Smut-balls, light kernels and chaff rise to the surface and are skimmed off. After the seed has soaked in this solution for about five minutes the solution is drained off into the lower tub. The grain is then emptied out into a pile on a clean floor or canvas. The position of the tubs is now reversed and the process repeated. The treated grain should be covered for four hours, to allow the formalin to act, and then spread out to dry. Grain should be sown the day after it is treated, if at all possible, as considerable injury to germination may result if treated grain is stored for a longer period. Wheat swells considerably due to the absorption of water and due allowance must be made for this in setting the drill for seeding. A whole series of treatments may be run with the same solution, but as each bushel of grain takes up about one gallon of liquid additions of fresh solution must be made to keep it up to volume. After the day's treatment has been finished all formalin solution that has been made up, both used and fresh, should be thrown away, as formalin solution changes in strength on standing and therefore cannot be relied upon if used the following day.

(c) Immersion by dipping.—Instead of immersing the seed in bulk, the seed may first be placed in bags and then dipped in the solution. Bunt-balls, of course, are not removed in the treatment and it is no more efficient than the

sprinkle method. But where small fine seed, such as grass seed, is to be treated, the dipping may be quickly repeated until a thorough wetting of the seed has been obtained. With the sprinkle treatment small seed sticks to the damp shovel and, therefore, it takes a longer time to carry out the treatment. Dipping the seed is also handy where it is desired to treat only a very small quantity.

Coarse sacks are filled with not over a bushel of seed each and tied loosely. If it is desired to treat larger lots of seed, a block and tackle are necessary for lowering and raising the bags. Two oil-barrels are filled half full with formalin solution. The bag to be treated is dipped into the solution and then lifted up and down several times to drive out all the air held between the seeds and thus allow all the grain to become wet. When the bag is immersed there should be sufficient solution to cover it three or four inches. After the seed is soaked five minutes in the formalin the bags are lifted out and allowed to drain. When the excess of liquid has drained off, the seed is emptied out into a pile on a clean floor or canvas and covered with clean bags or canvas for four hours. The grain is then spread out to dry. If the bags are drained well after treatment, the grain will be as dry after four or five hours as it would have been if the sprinkle treatment were employed.

Special machines have been devised to facilitate the treating of grain for smut. Most of them possess no special merit except that they may insure a more thorough wetting of the grain, if properly operated. One machine which we have seen deserves special mention in that it is designed to float out the bunt-balls from the grain and then skim them off. When bunt-balls are present, it would be much easier to operate a machine of this type than to immerse the seed in bulk by hand.

"Formaldehyde Gas" Treatments.—Since formalin is a solution of formaldehyde gas in water, it is evident that in the formalin treatments it is the presence of the gas in the water that is responsible for the control of the smut. This led to the idea that formaldehyde gas might be used directly to destroy the smut spores thus avoiding the disadvantages of a wet treatment. To obviate the difficulty of transporting and handling a gas, paraformaldehyde has been considered as a source of formaldehyde. Paraformaldehyde is a white powder, a distinct chemical compound formed by the union of two molecules of formaldehyde. It is seen occasionally when a vessel containing formalin is allowed to stand open to the air. The milkiness of the solution is due to the formation of paraformaldehyde.

The properties of paraformaldehyde, however, preclude its use as a fungicide. Although paraformaldehyde is formed rather readily from formaldehyde, very little of the latter can be obtained when paraformaldehyde is heated. When cooled it is deposited again in its original form. It can, therefore, be seen that paraformaldehyde is a poor source for formaldehyde gas. Besides, when seed is treated with formalin and then thoroughly dried, only a part of the formaldehyde evaporates; the remainder changes to paraformaldehyde and is left as a deposit in and on the seed coats. It has been conclusively shown that it is this substance which is responsible for the injury to germination.[36]

It was, therefore, not unexpected that a gas grain-pickler put on the market in recent years proved to be a failure when thoroughly tested. It was found that when the gas generated by heating the paraformaldehyde was conducted through a perforated pipe into the grain, the greater part of the paraformaldehyde was deposited on the pipe or on the grain near the perforations of the pipe. The germination of the whitened grain was completely destroyed. Grain further away was not injured, but the bunt in it was not controlled by the

[36] Hurd, Annie May. Jour. Agr. Research 20:209-244. 1920.

treatment. The farmer is, therefore, strongly advised to use a treatment that has been shown by controlled experiments to be safe and effective, if he wishes to get results that are always safe and satisfactory.

Precautions.—Formalin is a solution of formaldehyde gas in water and should contain not less than 40 per cent formaldehyde by volume. Although formalin in small containers is more expensive, its purchase in that form is recommended rather than in bulk, because the quality and strength can be relied upon. Formalin should always be kept in a well-stoppered bottle. If the solution becomes cloudy on account of the formation of paraformaldehyde, it should be gently warmed until the cloudiness disappears.

In making up formalin solution care should be taken to see that the proper strength is obtained. For wheat bunt one pound of formalin is added to forty gallons of water. For smaller amounts, one ounce of formalin is added to every $2\frac{1}{2}$ gallons of water. Stronger solutions cause marked injury to the germination of the wheat, while weaker solutions fail to control the bunt. Formalin solution should be made up only as required. Any solution not used on the day that it is made should be thrown away, as it increases indefinitely in strength by the more rapid evaporation of the water and, consequently, may injure the germination of any seed treated with it.

As formalin destroys only the spores that are on the seed at the time of treatment every precaution should be taken to prevent reinfection. All dust and dirt should be swept up from the floor before treating is begun. All bags which have held bunted wheat should be dipped in the formalin solution and dried before treated grain is placed in them. Shovels or other tools should be washed with the solution before they are used for handling treated grain.

On account of the difficulties in drying grain, as little water as possible should be left on the grain after treatment. In the sprinkle treatment, only sufficient liquid should be applied to thoroughly wet every grain. With the immersion treatments, time should be given for the excess to drain off.

Moist grain must not be exposed to temperatures below freezing (32° F.), as its germination will be seriously affected.

Grain should be sown the day after it is treated if at all possible, since considerable injury to germination may result if grain treated with formalin is stored for a longer period.

Wheat swells considerably owing to the absorption of water and due allowance must be made for this in setting the drill for seeding.

LOOSE SMUT OF WHEAT

(Fig. 3d.)

Appearance in field.—The observant farmer will be acquainted with another "smut" disease in wheat very different from bunt. This kind of smut becomes noticeable in the field at the time when the heads are being formed. Infected heads will be found covered with a black, sooty powder, which is readily shaken off on touching. At harvest time, only the central axis of the ear will be left, and no grain will be produced. This smut is the loose smut of wheat, and is readily distinguished from bunt by the distinctly black spore powder which is produced loosely without any covering.

Related to, but biologically distinct from, loose smut of barley.—The loose smut of wheat closely resembles the loose smut of barley, and the two fungi causing these diseases appear practically identical under the microscope; but they are nevertheless quite distinct. Cross-inoculation experiments have shown that spores of loose smut of wheat will not infect barley, while spores of barley loose smut fail to infect wheat. These two fungi are so highly specialized that

they are incapable of infecting other than their own particular host plants; spores of loose smut of wheat infect only wheat, while spores of loose smut of barley infect only barley.

Loose smut of wheat is therefore considered to be caused by a distinct fungus, called *Ustilago Tritici* (Pers.) Rostr.

LIFE-HISTORY OF LOOSE SMUT OF WHEAT

As already noticed, the smutted heads are produced at heading time, and the black sooty powder, composed entirely of spores, quickly disappears, so that at harvest time only the central axis of the head is left. As these spores are very light and easily detached from the head, they are gradually shaken loose by the waving of the grain and carried away by the wind. They may settle on all parts of the neighbouring plants as well as on the soil and other objects. The importance of the distribution of the spores at that time and other facts in the life history will be fully discussed in the subsequent sections.

Spores ripe before wheat is in flower.—On carefully looking into the subject, it will be noticed that the smut spore powder is produced before, or just at the very time, the normal or sound heads are in flower. As soon as the flowering period is over the first crop of smut spores is dispersed. However, a second and even a third crop of infected heads may be produced from an infected wheat plant, which will produce ripe spores at the same time as the healthy plant produces its second or third crop of heads. Again just after the flowering period of these secondary heads is over, the smut spores which have been produced will have disappeared.

Significance of the time at which spores ripen.—This fact of the dispersal of the spores taking place at the time of flowering of the wheat plant is no mere coincidence, it is the most important factor in the whole life history of the fungi producing loose smut in wheat and barley.

After many years of research on this problem, the repeated failure of all investigators to reproduce loose smut in wheat by spore infection of the young wheat plant, which so readily takes place in bunt or stinking smut, seemed to indicate that the solution of this question would lie in a different direction. Naturally it was at first expected that the spores of loose smut would adhere to the wheat grain and germinate as the seed grew, or that the spores present in the soil would remain alive over winter and infect the new crop in the spring. The life history of bunt, the spores of which grow so readily in artificial culture even years after harvest, of course influenced the opinions advanced. But the spores of the loose smut fungus persistently refused to germinate, and, indeed, as was shown later on, they retained their vitality for a few months only.

Flower infection takes place.—It was then that the independent researches of Brefeld[37] and Hecke[38], as late as 1903-1904, conclusively proved that the loose smut diseases are perpetuated through flower infection, confirming in this manner the results of the earlier experiments carried on by Maddox[39] in Tasmania in 1895 and later, viz., "that putting smut germs on the ovary about the time the pollen is ripe will always reproduce the disease the following year." Thus the mysterious connection existing between the production of ripe smut spores just at the time when the wheat is in flower was explained. Until recently this

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[37] Brefeld, O. Nachr. Klub. Landw. Berlin. 466:4224-4232. 1903.
[38] Hecke, L. Ber. Deut. Bot. Gesell. 23:248-250. 1905.
[39] Maddox, F. Agr. Gaz. Tasmania 4:92-95. 1896.

FIG. 9.—The wheat flower and flower infection with loose smut. 1. A head of wheat in flower (natural size); (*a*) anthers. 2. Single spikelet of a wheat head; (*a*) anthers. 3. Female organs of a flower; (*b*) the feathery style; (*e*) ovary; (*f*) ovule. 4. Part of style (*b*) covered with pollen-grains (*c*). 5. Pollen-grains (c), some showing germ-tubes (*d*). 6. Section of wheat grain showing young plant (*h*). 7. The young plant removed from the wheat grain, still further enlarged; (*g*) the "scutellum" or disc, through which the young plant absorbs its food from the rest of the grain; (*h*) growing point; (*i*) the primary root; (*j*) the sheath; (*k*) secondary root; (*l*) mycelium of the loose smut fungus in the tissues of the grain here represented by black lines. 8. Part of the style (b) showing a loose smut spore (*n*), pushing its germ-tube (*o*), into the tissues of the style. 9. Miscroscopical preparation showing masses of dormant mycelium (*l*) of the fungus in the tissues of the grain (*m*). (1-6 from "The life of the wheat plant"; 7 after Hecke; 8 and 9 after Lang.)

was the only demonstrated mode of infection, but Tisdale and Tapke[40] have succeeded in infecting barley with loose smut by dusting the spores on dehulled seed.

The flower of the wheat plant.—To comprehend thoroughly the following discussion of the life history of this smut, let us briefly study the flower of the wheat (see fig. 9; 1-5). In Canada, towards the end of June or in July a young head of wheat will show a large number of fine, yellowish appendages protruding from the upper part of the scales which later on enclose the mature grain (fig. 9; 1). These are the stamens of the wheat-flower with their large anthers containing the pollen, or male reproductive bodies (fig. 9; 5 c, d). When the scales of the flower are carefully removed the remaining parts of the flower, consisting of two thin, fringed scales, and the pistil with two feathery styles are exposed (fig. 9; 3 b, e, f.). When the pollen in the anthers, or pollen-sacs, is ripe, these burst, and the pollen-grains (fig. 9; 5) are discharged and caught by the feathery styles, where they are held fast (fig. 9; 4). Here they soon begin to germinate and the pollen-tubes push their way down through the style and ultimately reach the ovary, and fertilization of the ovule results.

Germination of loose smut spores.—The spores of the loose smut of wheat are considerably smaller than those of wheat bunt (fig. 1; b). On germinating in suitable media, the spores develop simple or slightly branched germ-tubes, but no conidia are produced (fig. 4; C. 1-3). It is readily seen that this mode of germination is entirely different from that of the spores of the covered smuts in which conidia are produced in abundance.

Details of flower infection.—Heads affected with loose smut are first evident at the time the wheat is in flower. Spore dispersal follows rapidly, beginning as soon as the heads emerge from the sheath. Of the many spores produced, most of them fall to the ground or adhere to the leaves and stems of the wheat or other plants. A few, however, may lodge on the stigmas of the wheat flowers. When this takes place, the spores germinate and push their germ-tubes down through the styles (fig. 9; 8), and finally into the ovules. The method employed by the fungus spores for reaching the ovules of the wheat plant is very similar to that used by the pollen-grains. When once within the developing seeds, the germ-tubes of the fungus branch and produce a very limited mycelium.

Smut fungus lives in the grain.—During the development of the grain the mycelium of the smut fungus now within it makes little growth, but remains alive. Throughout the winter it lies quite dormant like the seed itself. When infected seeds germinate in the spring, the mycelium again becomes active. Every infected grain will give rise to an infected wheat plant, the heads of which will contain a new crop of spores, and thus a new life-cycle will begin. The filaments or mycelium of the fungus were first successfully demonstrated in the tissues of the young plant by Hecke. Later, in 1910, W. Lang[41] obtained convincing evidence of the germ within the grain (fig. 9; 9).

Loose smut cannot be controlled by formalin.—From this account of the life history, it will be readily understood that this smut cannot be controlled in the manner prescribed for bunt. Since the germ of the disease lurks within the embryo of the grain, no surface disinfection of the seed will be effective. Some treatment which will kill the fungus but which will injure the germination of the seed as little as possible must be used.

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[40] Tisdale, W. H. and V. F. Tapke. Jour. Agr. Research 29:273-284. 1924.
[41] Lang, W. Centralbl. Bakt. Part 2, 25:86-100. 1909.

HOT WATER TREATMENT

The hot-water treatment was discovered by Jensen[42] of Denmark in 1887. He found that hot water at certain temperatures destroyed the germination of smut spores without injuring to any marked extent the germination of the grain to which the spores were adhering. Accordingly the method was employed at first to control wheat bunt, oat smut, and other smuts, which cause seedling infection. Later, however, the method was improved so that it could be used to destroy the dormant mycelium of the loose smut within the seed without causing serious injury to the seed itself. No more satisfactory treatment has since been devised.

Essentials of the hot water treatment.—The hot water treatment consists of two parts. First the seed is soaked in warm water (86° F.) for four hours and then the swollen grain is immersed for ten minutes in water kept during this time at a constant temperature not below 122° F. and not above 126° F.

Effect of hot water treatment on germination.—Although the hot water treatment effectively eliminates loose smut from the crop, it also causes considerable injury to the germination of the seed. The germination of good sound grain will be reduced from six to ten per cent, while with ordinary machine-threshed grain or seed of low vitality the reduction in germination is much greater. In his recent and very thorough study Tapke[43] found that when the seed coat, especially the area over the embryo, had been injured the germination of the seed was greatly reduced by the hot water treatment. Seed with unbroken coats germinated more slowly, but there was little reduction in germination. Injury to the seed-coat occurs in all seed threshed by machine; the degree of injury depends on weather conditions during ripening, cutting, and threshing of the crop. The loss of germination was considerable, for in 58 samples of machine-threshed grain the hot water treatment reduced the germination 33·3 per cent. The farmer should never treat grain of poor quality or badly broken and cracked seed by the hot water method. The loss in germination should be made up by increasing the rate of sowing.

Raising one's own seed supply from pure seed.—The solution of the loose smut problem lies in the practice of growing one's own seed grain, starting with clean seed grain or such as has been treated with hot water. Where two varieties of wheat are equally satisfactory from an agronomic standpoint, it is advisable to select the one that is the less susceptible to loose smut. The relative susceptibility of many varieties is not known, but it has been found that most of the commoner varieties are but slightly affected with loose smut. The notable exception is Kota wheat. One field of this wheat was observed in 1926 with 23 per cent of the heads destroyed by loose smut, while the destruction of ten per cent of the heads has been commonly observed. Ever since Kota wheat was introduced into Western Canada loose smut has been observed more and more commonly in this variety.

Method of securing smut-free seed grain.—A farmer may begin the first year by securing, say, three-quarters of a bushel of the very best wheat of that variety which has given the greatest satisfaction in his neighbourhood. This small quantity is easily subjected to hot water treatment in the way to be described presently, and it will suffice to sow one-half acre. It is important that this half-acre plot should be as far as possible removed from any other wheat field in order to prevent smut spores from being blown over from an infected field.

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[42] Jensen, J. L. Jour. Roy. Agr. Soc. England. (II) 24:397-415. 1888.
[43] Tapke, V. F. J. Agr. Research 28:79-97. 1924.

In spite of these precautions some smut spores will almost invariably reach the flowering plants and cause infection, if conditions are favourable. However, if available shelter from trees or shrub plantings is made use of in choosing land for the seed-plot, no serious infection is likely to take place.

If the treatment has been successful, and that will depend upon the amount of care with which it has been practised, the smut should be entirely absent from this one-half-acre plot. It would be advisable, however, to examine carefully the plot before flowering time and remove at once every plant, roots and all, of wheat that shows a suspicion of smut. This removal of affected plants may safely be carried on before the spores are ripe, and this is the correct time to remove them, else the very act of gathering heads with ripe spores will scatter them wholesale, and the walking through the plot with a handful of gathered smutty heads will be the very best method of infecting the flowering grain, which would otherwise have remained free from smut. This should be well borne in mind. As soon as the spores are ripe infection will have taken place to a large extent, but removing the plants carelessly will give opportunity for increased infection. It is advisable to provide paper bags and carefully draw the heads of an affected plant together, invert the bags over them, and then cut off all the heads. The plant should then also be pulled up.

The yield of this seed-plot should be quite free from smut. Under ordinary conditions it would yield 10 to 15 bushels of grain, or sufficient to sow 6 to 10 acres the next year, the yield of which would provide seed for a considerable area.

It is just as easy to treat 5 bushels of wheat as $\frac{3}{4}$ bushel, and, where the experimental treatment has proved successful, the farmer might well start with five bushels of treated seed.

The seed plot should be maintained each year; by paying additional attention to the quality of the strain of wheat selected for the "first seed plot" the benefit from such a plot would be largely increased. Moreover, it has been noticed[44] that when loose smut has been eliminated by seed treatment for one year, it only slowly increases, and some years pass before it is as serious as it was before the seed was treated.

How the hot water treatment works in the United States.—For some years it was noticed in the United States that loose smut was causing considerable losses to soft winter wheat. On this account some of the States where this wheat is grown, particularly Indiana and Virginia, made an effort to induce the farmers to treat their seed. Community seed-treating plants[43] were established in 1918. and quickly became popular. Many of these plants were located at creameries, canneries, mills, or other establishments, where a supply of live steam was available. Here the farmers brought their grain and treated it in small quantities in sacks. Where large amounts of wheat were to be treated, this method was too slow, and a special drum and tank for applying the 10-minute treatment was devised. The drum was made of heavy small-meshed wire or perforated sheet iron and was large enough to accommodate 5 bushels of soaked grain at one time. It was mounted so that it could be lowered and raised in the tank, and rotated when it was submerged in the hot water. By rotating the drum in the water uniform contact with the hot water was obtained. After the treatment, the grain was spread out to cool, then sacked and returned to the farmer. A charge of about 25 cents per bushel was made, to pay for the actual cost of operating the plant.

Grain subjected to hot water treatment is free from all kinds of smut.—It may be pointed out here that any kind of grain treated with hot water requires no separate treatment for other kinds of smut, as the hot water will destroy the

[44] Gregory, C. T. Proc. Ind. Acad. Sci. 1922:315-318. 1923.

spores of all smut diseases. We do not consider it necessary to treat with hot water seed grain obtained from the seed-plot, or even that produced under field conditions under the circumstances described, unless, of course, loose smut has become re-established. Then the hot water treatment should be resorted to again. We do recommend, however, that the wheat be treated with copper carbonate or formalin for the other kinds of smut, if it has not been subjected to the hot water treatment.

Reasons for the success of hot water treatment.—Appel, who has largely contributed to our knowledge of the control of loose smut, points out that the spores of loose smut will germinate in artificial media after four hours, when kept at a temperature of 77° F. He was of the opinion that the mycelium resting in the wheat germ might be stimulated into activity in the same brief period of time by immersing the infected grains in water of this temperature. That is to say, the resting fungus may be awakened from its condition of rest before the wheat grain itself would be influenced in a like manner (i.e., start to germinate), which may be considered out of the question within four hours. Hence it was reasonable to believe that the action of water of a higher temperature would destroy the germ of the disease, now in a more vulnerable state, without exerting too injurious an influence upon the life of the grain. It has already been pointed out that injury is actually caused to a certain extent, but loose smut is satisfactorily controlled by these means, and it is at present the only method known.

Jensen's original hot water method has been considerably modified owing to the researches, particularly of Appel, who demonstrated that soaking the grain previous to the real hot water application is of decided advantage. We have explained the scientific principles of such treatment, and will quote some interesting figures given by Appel[45], which show the results very convincingly.

It was first necessary to demonstrate whether previous soaking followed by the main treatment would reduce the smut disease, and what temperature would be the most advantageous. Wheat was soaked for four hours, or the time which it took the spores to germinate, at 77° F. Other temperatures also were used. The wheat was then treated with hot water in the usual way, with the following results:—

Temperature of water of preliminary soaking..	34° F.	48° F.	64° F.	86° F.
Percentage of smut noted in field plot..	4.6%	3.1%	1.1%	0%

The percentage of smut in the untreated check plot was 4·9%.

In addition, Appel investigated the question of the length of time necessary or most advantageous for the preliminary treatment. Some of the same wheat as used in the first experiment served the purpose.

Length of preliminary treatment..	2 hours	4 hours	6 hours
Percentage of smut noted in field plot..	2.7%	1.1%	0%

In this experiment the temperature of the water was 64° F.

The conclusion drawn from the above experiments, of which a considerable number were performed, is as follows:—

"It is thus shown that a reliable method for the control of loose smut of wheat (and barley) has been discovered, viz., soaking the grain for a period of from 4 to 6 hours in water of a temperature from 68° F. to 86° F., followed by a treatment with hot water at a temperature not below 122° F. and not above 129° F."

The next point to consider is the length of time required for the "main" treatment, i.e., the exposure to the hot water. This will depend to some extent

[45] Appel, O. Ber. Deut. Bot. Gesell. 27:606-670. 1909.

upon the facilities for maintaining the correct temperatures, but the general rule is 10 minutes at an even temperature of 124°-125° F.

The farmer will immediately realize that there are some serious objections from the practical point of view to this treatment, but then it must not be forgotten that at the present time this method is the only one known to control loose smut. After all, the apparent difficulties may be largely overcome by systematic work, and, by the exercise of care, this treatment will give highly satisfactory results.

SIMPLE METHOD FOR HOT WATER TREATMENT

(a) Preliminary Treatment (soaking)

Apparatus required.—1. One reliable thermometer; the ordinary bath-tub or room thermometer is very undesirable for this purpose, but a good dairy thermometer will serve the purpose well.

2. One large wooden barrel or any kind of metal tank or large vat.

3. A number of good strong grain bags which will allow the water to pass through rapidly.

4. Some kind of stove, boiler, or fireplace to heat the water.

Procedure.—1. Heat water in the boiler to almost boiling. Pour into large barrel or tank (before proceeding further refill the boiler with water) and add slowly, with vigorous stirring, cold water until the temperature is exactly 86° F. Unless the water is well stirred the correct temperature cannot be taken. Read the temperature without removing the thermometer from the water. The mercury bulb should always remain submerged when taking the reading.

2. Fill grain bags three-quarters full with the grain to be treated and tie them up loosely. Immerse into barrel with water at 86° F., move bag several times up and down, which will force out the air quickly. Take care the water covers the grain at least several inches. Allow the grain to remain in this water four hours.

Note.—The temperature of the water will become lower when the grain is introduced. Should it cool down too quickly, i.e., sink below 68° F., allow five hours for soaking.

Treat the grain, if possible, in a heated room to prevent the rapid sinking of the temperature. By placing the barrel or tank in a large wooden box, tightly packed with wood shavings, hay or straw all around, and covering it with a lid, the temperature remains fairly constant for four hours, once the grain has assumed the temperature of the water. One ordinary barrel will treat about one bushel of grain or a little more. Use two or three barrels or one of larger size if more grain is to be treated. The larger the barrel and the greater the volume of water, the more easily will the temperature be kept constant.

(b) Main Treatment with Hot Water

Additional requirements.—Two large barrels or vats, each capable of holding from two to three bags of grain. A water can with a sprinkler attached.

Procedure.—Into the first barrel pour a quantity of nearly boiling water and add cold water slowly until the temperature is accurately 112° F. (Fill up the boiler immediately, as more water will be required in a short while.) Then take out the grain from the "soaking" barrel and place in this one. Move several times up and down and allow to remain for 15 or 20 minutes.

Meanwhile prepare the other barrel; pour in hot water as near boiling as possible, add cold water slowly, with stirring, until the temperature is exactly

129° F. Then take the bags out of the second barrel (the one with the water at 112° F.) and place in the barrel with water at 129° F. This will cause the temperature to sink to some extent; should it sink below 122° F. fill the sprinkling can with hot water and sprinkle into the barrel, but under no circumstances upon the grain or the bags containing it. When, however, the bags are well covered with water, at least four or five inches, the hot water may be safely added. To mix it with the whole contents lift the bags up and down, or move them around the barrel. The grain must remain for exactly ten minutes in this last barrel, during which time the water should be maintained evenly at a temperature from 124° F.-127° F. It should never sink below 122° F. nor be hotter than 129° F. The former will be ineffectual in killing the smut, the latter will cause unnecessary damage to the grain.

(c) Drying the Treated Grain

Of all the difficulties of this hot water treatment, the complaints about the trouble in drying the grain after treatment exceed all others. When taking the bags out allow them to drain thoroughly. On sunny days the grain may be spread out in a thin layer in the open air, when shovelling or moving it with a wooden rake will render it sufficiently dry for sowing in a few hours. It is necessary to emphasize the caution that should be taken as regards the reinfection of treated grain, which subject has been fully dealt with under the chapter on stinking smut. When the temperature is below freezing, or on dull or rainy days, the grain should be spread out in a thin layer on the clean, dry floor of the barn. It is most important to keep on shovelling the grain over to allow of air being mixed with it, when it will dry far more quickly. Besides, grain, which is left lying untouched, is liable to become mouldy, and this will destroy its germination. At times, especially on dull days, it is advisable to chill the grain by placing the bags for a minute or two in cold water, moving the bags several times up and down before spreading it out for drying. This has been found of advantage, especially when barley is being treated. In rare cases, grain has begun to sprout while spread out for drying. This causes no harm whatever, providing the grain is sown before it is absolutely dry. In the laboratory, we have found that grain, that has sprouted and has been allowed to get fairly dry, will revive completely, when sown without much delay, and grow just as well as untreated seed.

FLAG SMUT OF WHEAT

(Fig. 10)

Flag smut of wheat has long been known in Australia and certain Asiatic countries. Its first appearance in North America was in the United States in 1919. At first it was confined to a few counties in Illinois, but it has since spread across Missouri and into Kansas. Up to the present flag smut has not been found in Canada. Accordingly only a brief description of the appearance and control of this disease will be given. It is earnestly requested that, in cases where flag smut is suspected, specimens of the plant be sent in immediately to the Division of Botany for examination.

Appearance in the field.—Flag smut, as the name implies, is found principally on the leaf sheath and the flag or the blade of the leaf, but it may also occur on the stem and even on the glumes. The affected leaves are curled and distorted and on them appear fine black longitudinal streaks. These black stripes are due to the spores produced by the fungus. Most of the leaves on the stem are infected, but the upper leaves are most severely injured. Infected stems are usually dwarfed, not growing to more than one-half or two-thirds the height

FIG. 10.—Flag smut of wheat, after McAlpine, "Smuts of Australia".

of the healthy stems, and they rarely head out or produce seed. Usually all the stems of a plant are infected, but occasionally a plant may produce both healthy and diseased stems.

Causal Organism.—The smut fungus, *Urocystis Tritici* Koern., causes flag smut of wheat. Other species of *Urocystis* are responsible for the economically important diseases of stem smut of rye and onion smut. The spores either occur singly or two or more are united together into a spore ball. Either the single spore or the spore ball is covered with a layer of sterile empty cells. On germination the spore produces a promycelium, on the tip of which two to four elongate sporidia develop. From the way the spores germinate it is evident that the genus *Urocystis* is closely related to *Tilletia*, but, on account of the occurrence of the spores in balls more or less covered by a sterile envelope of cells, *Urocystis* is considered a distinct genus, the third to be described.

Sources of infection.—Infection from flag smut takes place either from spores on the seed or from spores in the soil. In threshing an infected crop a large proportion of the spores are knocked out and are scattered over the grain. The threshing-machine, waggon-box, granary, bags, or other tools for handling grain, may become covered with spores and in this manner the infection is spread to clean grain.

While harvesting an infected crop, dead leaves and other plant parts carrying spores are broken off and fall to the ground. A field that has borne a smutty crop is thus contaminated with spores. Infection may also be caused by infested straw or manure put on the land, or by wind-borne spores.

Control.—Copper carbonate or formalin as recommended for wheat bunt will destroy all seed-borne spores.

To avoid infection from the spores in the soil, wheat should not be sown on land that has borne a smutted crop the previous year. One or more years should elapse before wheat is again sown on this land. All infected straw should be destroyed and not allowed to get into the manure, this being carried back to the land.

In the United States[46] flag smut has occurred more frequently on certain very susceptible Australian varieties of wheat, but both soft and hard winter wheats of high commercial quality have been found that are immune or highly resistant to it. The resistance of hard red spring varieties such as are commonly grown in Western Canada has not been determined.

SMUT DISEASES OF BARLEY

(Fig. 11)

Barley is subject to two kinds of smut.—For many years the barley smuts were considered to be all one smut disease. The older writers gave the name *Ustilago nuda* to the causal organism. But seed treatment gave contradictory results, sometimes controlling the smut in barley and at others failing to do so. This seemed to indicate that the treatment had its limitations and was of restricted value as far as barley was concerned. Later closer study showed that barley was subject to two kinds of smut, a covered smut, *Ustilago Hordei* (Pers.) Kellerm et Swingle, and a loose smut, *Ustilago nuda* (Jens.) Kellerm et Swingle. This discovery at once accounted satisfactorily for the failure of seed treatment to control the smut. The seed treatments then in use readily eliminated covered smut, but were ineffective against loose smut. The hot water treatment, which was discovered about the same time, however, was soon found to control loose smut.

[46] Tisdale, W. H., et al Ill. Agr. Exp. Sta. Bul. 242. 1923.

FIG. 11.—The smuts of barley. (*a*) Heads of barley destroyed by loose smut. (*b*) Head of barley affected with covered smut

COVERED SMUT OF BARLEY

(Fig. 11; b)

Appearance in the field.—Covered smut of barley is most readily recognized after the grain is cut. In the field it may be mistaken for loose smut, which it resembles at times rather closely. The heads affected with covered smut retain the general shape of the normal heads, but are much smaller. The kernels as well as the covering glumes, except their tips and awns, are completely transformed into smut. In the normal heads there are three spikelets at each joint of the rachis, or axis of the head, but in the smutted heads the lower halves of the spikelets fuse, the upper portions remaining distinct. The smut masses are covered with a delicate white membrane, while the black spores within show through the membrane and impart a dull gray colour to the head. This membrane usually remains intact and prevents dispersal of the spores until threshing time. The smutted heads are then broken up and the seed becomes contaminated.

Germination of the spores.—These spores differ from those of the loose smuts and of wheat bunt in appearance (fig. 4; A, 8) and still more in their mode of germination. They are slightly larger than those of loose smut of wheat and are perfectly smooth and olive brown. In nutrient solutions they germinate freely, producing short, stout germinal tubes divided by septa, or cross-partitions, into four cells. At the septa conidia are produced, which multiply, even if detached, after the manner of brewers' yeast. Such cultures may continue to grow for a considerable time, during which the conidia increase greatly in number, but, after a time, the budding ceases and these spores produce thread-like tubes. When barley seed contaminated with spores of covered smut is sown, the spores germinate and similar tubes penetrate the tissues of the seedlings and eventually give rise to smutted plants.

Treatment.—The formalin treatments, as outlined for wheat bunt, effectively control covered smut of barley. Of these the formalin sprinkle is recommended, as it is the least laborious to carry out. Sometimes the smutted heads are only partially broken up in threshing and large firm masses of spores are found scattered about in the grain, just as bunt-balls are found in wheat. Under these circumstances the formalin immersion treatment is better, as it removes the masses of smut and guards against reinfection of the treated grain.

The copper carbonate treatment has not given satisfactory control of this smut and is, therefore, not recommended.

LOOSE SMUT OF BARLEY

(Fig. 11; a)

The loose smut of barley is very closely related to loose smut of wheat. Taking into consideration its general symptoms and the life history of the fungus, one might be led to believe it to be the same species as found in wheat. Yet the fungi are biologically different, for the fact that the smut of wheat cannot infect barley, and that of barley cannot infect wheat, is significant enough to show that the fungi are different species.

As in loose smut of wheat, this smut completely destroys the grain, and the spores appear as loose powder at the time the barley is in flower. In the earlier stages, the affected heads may resemble covered smut, owing to a fine covering membrane which may be present, but this membrane soon disappears, and at harvest time there is left only the empty axis of the head, and in bearded barleys, the curved twisted awns.

The life history of the causal organism is very similar to that of the loose smut of wheat. However, it seems doubtful if in this case infection occurs only at flowering time. Tisdale and Tapke[47] infected barley with loose smut by inoculating the dehulled seed with the spores. The spores (fig. 4; A, 7) of barley loose smut are similar in size and other microscopic details to those of the loose smut of wheat. The spores are olive brown with one side a decidedly lighter colour than the other, while the whole surface is finely dotted. The germination of the spores is like that of the loose smut of wheat. No sporidia, or secondary spores, are produced, but the spores form more or less richly-branched infection threads.

Although a great deal of work has been done to find a simpler seed treatment, the hot water treatment, as described in detail for the loose smut of wheat, is the only treatment that is wholly effective, and it is, therefore, recommended for the loose smut of barley.

SMUT DISEASES OF OATS

(Fig. 12)

Prevalence of oat smut.—Smut in oats occurs far more commonly than smut in either wheat or barley. In Canada the oat smuts cause an annual loss of over $6,500,000, a loss greater than that caused by all the other smuts combined. As oat smut is readily controlled by seed treatment, no explanation of its prevalence is possible except that, through lack of knowledge or neglect, the farmer has not consistently treated his seed for smut.

Two smut fungi responsible.—Oat smut consists in reality of two smuts caused by two distinct fungi. At first glance all oat smut looks alike, but with careful observation it will be seen that two smuts may be distinguished, a loose or naked smut and a covered smut. Naked smut of oats is caused by the fungus *Ustilago Avenae* (Pers.) Jens. and covered smut is due to a closely related fungus *Ustilago levis* (Kellerm et Swingle) Magnus. Both the oat smuts are prevalent in Canada.

NAKED SMUT OF OATS

(Fig. 12; b)

Appearance in the field.—This species of smut destroys the head or panicle of the oat plant and appears as an almost black powder while the plants are still growing. The presence of peculiarly stunted heads is the first indication of smut in the crop. The normal panicle is open with the individual spikelets drooping gently under the increasing weight of the grains, but the diseased panicle is erect and the smutted spikelets stand close to the central axis of the head. The individual spikelets are almost completely transformed into black smut spores. Occasionally the smut appears as long black stripes in the uppermost leaf. These stripes eventually burst open allowing the spores to escape.

Dispersal of spores before harvest.—The dispersal of the ripe spores takes place mostly at the time of flowering. The spores (fig. 4; A, 2) are readily distributed by the wind. Some spores are carried to the healthy panicles and there lodge in cracks and crevices on the outside of the glumes, or they may fall inside between the glumes and developing seed. These spores remain dormant until the seed carrying them is planted, and then germinate and infect the young seedling as in the covered smuts.

[47] Tisdale, W. H. and V. F. Tapke. Jour. Agr. Res. 29:263-284. 1924.

FIG. 12.—The smuts of oats. (*a*) Covered smut of oats. (*b*) Naked smut of oats. Note the more natural appearance of the panicle affected with covered smut, compared with those infected with loose smut.

Recently,[48, 49] it has been shown that the spores frequently germinate immediately after they become lodged between the glume and the young seed. A mycelium is formed in the inner tissues of the glume and in the remains of the now useless flower parts, the stigma and anther filaments. When infected seed is planted the dormant mycelium germinates with the seed and attacks the young seedling.

Appearance and germination of the spores.—(fig. 4; D, 1-3).—The spores of naked smut of oats resemble those of the loose smuts of wheat and barley in size, and in the fine dotting of the spore wall, and in other microscopic details. On the other hand they germinate in a manner similar to the spores of covered smut of barley, producing a septate promycelium with many hyaline conidia, which reproduce themselves indefinitely in a yeast-like manner if conditions are favourable. When the spores germinate on the seed after it is sown, these conidia send out germ-tubes which penetrate the young oat seedling. When the spores germinate on the developing seed at flowering time the conidia produce hyphae which penetrate the inner wall of the glume and form a resting mycelium.

Treatment.—Formalin is the only substance recommended for the control of loose smut in the ordinary hulled varieties of oats. It alone has been shown to have sufficient penetrating power to destroy the spores or the resting mycelium of the fungus protected as they are by the glume. Copper carbonate or other substances used as dusts have not been found to be effective.

Both the formalin sprinkle and the formalin spray treatments are recommended for oats. The other formalin treatments control the smut satisfactorily, but are more laborious and the grain is difficult to dry on account of the more complete wetting. The sprinkle treatment is applied as described for wheat bunt.

For the formalin spray treatment, one pound of formalin is mixed with one pint of water. The oats to be treated are placed in a pile on a clean floor. As they are being shovelled over they are sprayed with the solution at the rate of 1 quart of solution to 50 bushels of grain. If it is desired to treat a smaller quantity of seed, the amount of solution added should be correspondingly reduced. A small sprayer (quart size) is most convenient for applying the formalin solution. The solution should leave the sprayer as a coarse mist. This treatment can be carried on best by two men; one man shovels the grain while the other sprays each shovelful. By spraying where there is a good circulation of air and with the sprayer held close to the grain, irritation of the eyes, nose and throat from the strong formalin fumes can be avoided. After the oats are all treated they should be piled in a heap and covered with blankets or sacks to confine the formalin vapour. The bags should be thoroughly clean, or be dipped into a formalin solution. After 5 hours the seed should be uncovered. It may then be bagged and sown immediately, for the grain does not become wet or swollen and, therefore, will not choke the drills.

The formalin spray, or " dry formalin," method is recommended only for the control of oat smut.

For hull-less oats the copper carbonate dust treatment is recommended. The details of this treatment are the same as they are for controlling wheat bunt, in which section they have been fully described. For hull-less oats a good brand of copper carbonate containing 50 per cent copper should be applied at the rate of 4 ounces per bushel†, or 1 ounce for every fourteen pounds.

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[48] Zade. A. Angew. Bot. 6:113-125. 1924.
[49] Diehl, O. Bot. Arch. 11:146-199. 1925. Abstract in Rev. Appl. Myc. 5:27. 1926.
† A bushel of hulless oats has been taken as weighing 56 pounds.

COVERED SMUT OF OATS

(Fig. 12; a)

Appearance in the field.—The covered smut of oats is noticeable first when the crops begin to head. At that time infected plants produce rather stunted smutted panicles similar to those infected with loose smut, except that the covered smut does not so completely destroy the panicle and replace it by spores. The outer glumes of each spikelet are only partially destroyed and, in consequence, the spores are not so easily blown away by the wind as in loose smut, and the spikelet retains its normal shape.

Spores dispersed at threshing time.—When smutted grain is threshed, the smutted heads are broken up by the thresher and the spores become scattered over the sound grain.

Appearance and germination of the spores.—The spores of the covered smut fungus are perfectly smooth (fig. 4; A, 9), differing in this respect from the finely echinulate spores of the loose smut fungus. On germination each spore produces a septate promycelium which, in turn, produces conidia. The conidia multiply indefinitely in yeast-like manner if conditions are favourable. When smutted seed is planted the spores germinate with the seeds and infect the young seedlings.

Comparison of the fungi that cause loose and covered smut in oats.—The two fungi that cause loose and covered smut respectively in oats are very much alike in some respects, but differ considerably in others. Heads infected with either smut appear at flowering time, but, on account of the more complete destruction of the head by the loose smut fungus, its spores are dispersed by the wind at that time and find lodging between the glume and the developing seed. The spores of the covered smut fungus on the other hand are not dispersed until the smutted heads are threshed, at which time they are scattered over the seed. Spores of both smuts may cause seedling infection, but seedlings may also be infected with loose smut by means of dormant mycelium in the tissue of the glumes. The spores of the loose smut fungus are seen to be finely dotted over the surface when examined under a microscope, while the spores of the other smut are perfectly smooth. Both fungi are readily controlled by the same means. In the common hulled varieties of oats the formalin spray and sprinkle treatments give excellent control. In hull-less oats, on the other hand, the copper carbonate treatment has proved most satisfactory.

Treatment.—To control covered smut in the common hulled varieties of oats, the formalin sprinkle or spray treatments are recommended. The sprinkle treatment has already been described under the control of wheat bunt, while the spray treatment is discussed in detail under the treatments for the loose smut of oats.

In experiments for the control of covered smut in common oats, copper carbonate has not always successfully held the disease in check. Where plots sown with untreated seed showed ten per cent or less of smut, copper carbonate reduced the smut to a negligible amount; but in cases where untreated seed produced a crop heavily infested with smut, copper carbonate only reduced the amount by about a half. Further trials will be necessary before the value of this treatment for covered smut of oats can be definitely decided.

With the hull-less oats, formalin does not effectively control this smut and causes serious injury to the germination of the seed as well. Hence copper carbonate should always be used with hull-less oats. A good brand of copper carbonate should be applied at the rate of 4 ounces per bushel (56 pounds), or 1 ounce for every 14 pounds of seed. The details of treatment have been described under the treatment for the control of wheat bunt.

FIG. 13.—Rye smut on heads and stems, showing the distortion and splitting of the stems. After Stakman, E. C. and M. N. Levine. Minn. Agr. Exp. Sta. Bul. 160 fig. 2, 1916.

STEM SMUT OF RYE

(Fig. 13)

Unlike the other grain crops rye is rarely smutted in Canada, although occasionally a field is found infected with stem smut. Usually the infection is slight, but in 1924 two fields were found in Manitoba in which 15 to 20 per cent of the stems were destroyed by smut.

Stem smut of rye is caused by *Urocystis occulta* (Wallr.) Rab., a fungus closely related to the flag smut fungus which attacks wheat.

Appearance in the field.—Stem smut appears on the leaves, leaf sheaths, and stems, as long parallel streaks. These streaks are most noticeable on the stems, particularly on that part just below the head, where they coalesce to

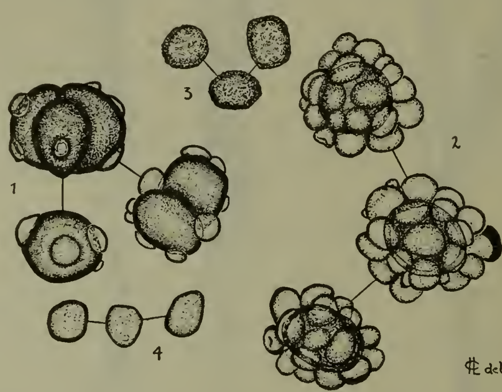

Fig. 14.—(1) Spore-balls of rye smut, the fertile spores only partially covered by the sterile spores. (2) Spore-balls of onion smut, one fertile spore in each ball almost completely invested by sterile cells. (3) Spores of western rye grass smut. (4) Spores of *Panicum* millet smut. All magnified 600 times.

form a densely smutted area. The streaks are due to masses of black or brownish-black spores within the leaf and are first lead-coloured, but later the epidermis becomes ruptured and the streaks appear black from the spores thus exposed. Smutted plants are usually stunted and mis-shaped. Heads are frequently formed, but they are pale, undersized, and usually completely blighted. They often hang vertically downward due to the stems being weakened by the smut just below the heads.

Appearance and germination of the spores.—The spores are dark golden-brown in colour, spherical to oblong in shape, and are about the size of bunt spores (*Tilletia*). They occur either singly, or as spore-balls (fig. 14; 1) in which from two to five are united together. In either case the surface is more or less covered with a layer of sterile empty cells. On germination, each spore produces a hyaline tube, or promycelium, at the top of which from two to four elongate sporidia develop.

Sources of infection.—Infection from stem smut arises from spores either on the seed or in the soil. When an infected crop is threshed, a large number of the spores are knocked out of the straw and are scattered over the grain.

When an infected crop is harvested, leaves and stems carrying spores fall to the ground and thus inoculate the soil. Spores carried by the wind, and infected straw or manure put on the land are also sources of infection.

Control.—The formalin sprinkle treatment as described for the control of wheat bunt is recommended. No experiments on the effectiveness of copper carbonate in controlling stem smut have been reported, although it has been found satisfactory against the related flag smut of wheat.

Difficulty in controlling rye smut has arisen only when rye has followed rye, year after year, on the same fields. To avoid infection from spores in the soil, at least a year, and preferably longer, should elapse before rye is sown a second time on a field that has borne a crop infected with rye smut. All infected rye straw should be burnt, but, if it is used for bedding, the manure should not be spread on land where rye is to be grown.

CORN SMUT

(Fig. 15)

Corn smut is found in Canada wherever corn is grown. It is caused by the fungus *Ustilago Zeae* (Beckm.) Unger, and is quite destructive in certain susceptible varieties of corn.

Appearance in the field.—Corn smut may occur on any of the above-ground parts of the plant. As will be explained later, the fungus attacks any young or actively growing part of the plant, such as the leaf axils, the midrib of the young leaves, and the flowers of the tassel or ears. It causes a local irritation of the plant in the infected area with the result that smut-boils of a characteristic appearance, and often of great size, are formed. The disease appears first on the leaves. Affected leaves turn a paler yellow than normal and are puckered with bladder-like swellings of different sizes. The swellings consist at first of a mass of smut mycelium mixed with plant tissue, but later the mycelium is transformed into spores. As the time of spore production approaches the colour of the affected tissues becomes rather variable. Quite frequently it becomes a deep crimson, but, whatever the earlier colour may have been, it later gives way to a silvery white. Up to this time the spores are still unripe and are enclosed within the variously shaped boils, which are covered with a stout parchment-like, but pliable, membrane. As the disease progresses the membrane grows thinner and thinner and finally bursts, whereupon myriads of spores in the form of a black powder are exposed. If the ears are attacked they are usually malformed, the kernels being replaced by smut-boils varying from the size of a pea to that of a walnut.

The appearance and germination of the spore.—The spores (fig. 4; A, 5) are brown, round to slightly oval, with a fine prickly surface and often granular content. The size of the spore is about double that of the loose smut of wheat or barley. On germinating, each spore (fig. 4; E, 1-4) produces a short stout four-celled promycelium, at the tip and cross-walls of which slender conidia are formed, as in the covered smuts. These conidia bud profusely under favourable conditions, and eventually become detached. Even the cells of the promycelium may separate and form smaller or larger clusters of yeast-like spores. Their development in artificial media is so rapid and vigorous that parts of the clusters may be forced up into the air, where they will branch and produce spores in long chains (fig. 4; E, 4). These spores are considerably smaller than those produced within the media.

Method of infection.—The method of infection with corn smut is unique. In the true loose smuts of wheat and barley, infection takes place through the flower, while in the other smuts already described the plant becomes infected in the seedling stage. In both these cases the infection of the plant is systemic. That is, the fungus gets established in the young plant when still a seedling, and

FIG. 15.—Smut of corn. (*a*) Male inflorescence or tassel partly infected. (*b*) A large "smut-boil" on the main stem. (*c*) Female inflorescence or ear destroyed by smut.

is present in all shoots that develop later. Finally it makes its appearance in the head or inflorescence, as in bunt or loose smut of wheat, or in the leaves or leaf sheaths, as in the flag smut of wheat. In the case of corn smut, however, the disease is not systemic. The fungus does not spread through all the tissues of the plant but remains localized. Each separate group of smut-boils arises from a distinct infection.

As has already been pointed out, when a smut-boil matures, the membrane covering the boil bursts, and thus permits the spores to be carried away by the wind or washed down into the soil by the rain. The smut-boil gradually disintegrates, liberating more and more of the spores. Bacteria and yeasts may get into the ripe boil and, by their action, greatly accelerate the disintegration. On reaching the soil, the spores readily germinate in moist organic matter, such as manure and decayed plant tissue, and produce conidia in abundance. The continued presence of moisture is not necessary for either the spores or conidia, as both are but little affected by drying. Consequently they may be blown about by the wind, along with other particles of dust, until they reach a favourable place to continue their growth. Some of these may lodge on corn plants. A rain washes them, as well as numerous dust particles, into the axils of the leaves, which now become filled with water holding a small amount of organic matter in solution. In this medium the conidia quickly begin to bud, and soon produce a virulent culture of corn smut. Any young growth in these leaf axils is thus in contact with the organism and may be attacked.

Weather affects smut.—From the foregoing it will readily be seen that the plant's chances of becoming infected depend a great deal on the type of weather prevailing during the growing season. Dry weather holds the disease in check, but wet weather favours its rapid spread. This can readily be noticed when rain follows a long period of drought. The moisture causes a rapid growth of the corn, resulting in the appearance of numerous young buds and tender plant parts which can be readily attacked by the fungus. Moisture thus serves two purposes beneficial to the fungus: it permits the rapid increase of conidia by budding, thus increasing the amount of inoculum, and it provides many additional points at which the fungus may find entrance.

Control measures.—Corn smut is a difficult disease to control since the smut fungus may attack the young growing tissue of the plant at any time throughout the seasons when conditions are favourable. Unlike most smut diseases, seed treatment is of little value except when corn is to be sown in a district where the disease is unknown. In this case treatment destroys seed-borne spores, which might otherwise introduce the disease.

Where the field is small all infected stalks, ears, and tassels should be removed and burnt. When possible the smut-boils should be collected before the spores are formed. If, however, spore formation has already begun, the infected parts should be put in paper bags as they are collected to prevent the spores from spreading around. The field must be gone over at frequent intervals, especially when the plants are growing vigorously some ten to fifteen days after a period of rain. Infected parts must never be thrown into a compost heap or manure pile, for there the smut spores will germinate and produce abundance of conidia in the decaying vegetable matter. When such manure is spread on a field, especially in the spring, the soil is actually inoculated with the corn smut organism and, if corn is sown there, a heavily smutted crop will almost invariably result.

If, for any reason, the smut-boils are not, or cannot be, removed from the plants in the field, it is preferable to convert the corn into ensilage, for in the silo a fermentation soon begins which, in the course of about three or four

FIG. 16.—Healthy and smutted heads of western rye grass. Photo by Fraser and Scott.

weeks, destroys the spores.[50] On the other hand, if the loose corn stalks were fed to stock, the spores are almost certain to get into manure and to be carried back again to the land.

In addition to these sanitary measures, crop rotation will be found of advantage. Corn should not follow corn in a rotation, as, by such a practice, the smut organism tends to accumulate in the soil.

SMUT OF WESTERN RYE GRASS

(Fig. 16)

Western rye grass (*Agropyron tenerum*) is one of the few native prairie grasses which has been brought under cultivation. About 1890 its value as a forage plant, both for pasture and for hay, was first recognized, and it is now grown extensively throughout Western Canada.

A smut is common on western rye grass in the Prairie Provinces of Canada. This smut is considered to be due to the fungus *Ustilago bromivora.*[51] It also attacks *Agropyron Richardsonii* and *A. dasystachyum,* two native wild rye grasses, and certain brome grasses, both cultivated and wild. It has never been found on awnless brome grass (*Bromus inermis*).

Appearance in the field.—On western rye grass this smut resembles in appearance covered smut of oats. The smut spores form little swollen masses at the base of each spikelet and the smutted heads ripen prematurely. On the brome grass the smut galls are usually much larger with the result that smutted heads are quite conspicuous.

Appearance and germination of the spores.—The spores (fig. 14; 3) are reddish brown, mostly oval-shaped or round, but occasionally irregular, owing to pressure from neighbouring spores during formation. They sometimes appear smooth or only granular, but usually are covered with very minute warts. Their size is about that of corn smut spores, while they germinate in a manner similar to those of the covered smuts already described.

Seedling infection.—The spores responsible for infection of cultivated stands of western rye grass are disseminated when healthy and smutted heads are threshed together. When seed contaminated with smut spores is planted, the spores germinate with the seed and the young seedlings become infected. Since many of the bromes and rye grasses are perennial and the smut lives over in the crown, any new heads developed by plants once infected are also smutted.

Control.—Steeping the seed for five minutes in the ordinary formalin solution (1 pound of formalin to 40 gallons of water) has given perfect control and no seed injury was evident. Copper carbonate failed to control the smut.[52]

LEAF SMUT OF TIMOTHY

Leaf smut of timothy occurs on timothy and on a large number of other grasses, some of the most important of which are red top, orchard grass, and Kentucky blue grass. It has been collected rarely on timothy in Canada, but has been reported to cause serious losses in the United States. In a comprehensive survey of New York State[53] in 1914, the disease was found to be more or less abundant in most fields examined. In one field over fifty per cent of the plants were infected, and the loss in hay was estimated at about thirty per cent.

[50] Piemeisel, F. J. Phytopath. 7:294-307. 1917.
[51] Fraser, W. P. and G. A. Scott. Phytopath. 16:473-477. 1926.
[52] Fraser, W. P. Dom. Div. Botany Report for the year 1922:55. 1923.
[53] Osner, G. A. Cornell Univ. Agr. Exp. Sta. Bul. 381. 1916.

The loss would have been even more if the crop had been intended for seed. The smut has been collected on some grasses in Canada, and its presence on timothy may have been overlooked.

Appearance in the field.—Timothy smut affects the leaves, stems, and heads. It appears at first as long narrow lead-coloured streaks in the leaves. The epidermis soon ruptures and these streaks turn dark-brown or nearly black from the dusty spore-masses exposed. The spores are soon scattered by the wind, while the leaves become very much torn and shredded. According to Osner[53] this shredded appearance of the leaves is one of the most striking symptoms in the older plants, enabling one to recognize the disease at a considerable distance. Affected plants are seriously dwarfed and produce few heads. The heads that are formed are usually completely destroyed by the smut and, consequently, practically no viable seed ever matures. Sometimes the infection is so severe that the young plant dies.

Fungus causing leaf smut of timothy.—The name usually adopted in this country for the fungus causing leaf smut of timothy is *Ustilago striaeformis* (Westd.) Niessl.

Appearance and germination of the spores.—The spores of the timothy smut fungus are about the same size as corn smut spores but are more prominently echinulate. On germination each spore puts forth a long germ-tube or promycelium, bearing from one to five lateral sporidia. In most features the germination of the spores resembles closely that of the spores of the true loose smuts. But unlike spores of most smuts, those of timothy smut require a long period of rest before they germinate[54]. Spores in the soil require on an average 265 days before they will germinate, and they are then capable of germination for about 72 days. Therefore only spores produced the previous season are capable of infecting the timothy seedlings.

Seedling infection.—The timothy smut fungus lives over winter as spores in the soil or in decaying smutted plants, or as perennial mycelium in the bulb-like bases of the plant. In the spring, over-wintered mycelium in infected plants grows up into the actively growing part of the plant, infects the new shoots, and produces in the leaves, stems, and floral parts the characteristic streaks of smut. Plants become infected initially only in the seedling stage from overwintered spores, the disease appearing in from five to thirteen weeks after infection.

Control.—As the life history of timothy smut was imperfectly understood until recently, previous efforts to control the disease have been unsatisfactory. Until experiments are conducted the following control measures are suggested.

The usual formalin dip or sprinkle treatments would destroy the spores on the seed, but they afford no protection from spores in the soil. If dusting the seed with copper carbonate would prevent infection from soil-borne spores, it would prove the best treatment for the amount of soil infection would also be reduced.

Where hay infected with smut is being fed, the manure should not be spread on land which is to be sown to timothy the following season.

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[54] Davis, W. H. Jour. Agr. Research. 32:69-76. 1926.

FIG. 17.—(a) Coverel kernel smut of sorghum on broom corn; (1) smut balls; (2) normal parts of panicle enclosing sound grain; (3) sound grain. (*b*) A head of fox-tail millet affected with smut.

SMUT OF FOX-TAIL MILLETS

(Fig. 17; b)

The commonly cultivated millets fall naturally into two groups—the fox-tail millets, which have a compact nodding spike-like head, and the *Panicum* millets, which have an open head somewhat like an oat panicle. The common, German, Kursh, Hungarian, and Siberian millets are of the fox-tail type, while the proso, hog, and broom-corn ones are of the *Panicum* type.

Although millet is not an important crop in Canada, it is sometimes grown and is occasionally found infected with smut. The fox-tail millets are attacked by the smut fungus, *Ustilago Crameri* Koern, which destroys the individual flowers, but does not alter the normal shape of the head. On the other hand the *Panicum* millets are subject to a smut caused by an entirely different fungus, which destroys the normal spreading panicle and, in its place, produces a thick elongated smut-boil, which will be discussed in the next section.

Appearance in the field.—This smut somewhat resembles in appearance stinking smut of wheat or the covered smut of oats, and in the field is very noticeable from the black appearance of the affected heads. The spores are either dispersed in the field, where they infect the seeds of neighbouring plants, as occurs in naked smut of oats, or they may remain enclosed in a membrane, forming smut-balls similar to, but much smaller than, those of stinking smut of wheat.

Appearance and germination of spores.—(Fig. 4; A, 3). The spores are reddish-brown, oval, round, or showing irregular indentations where they have been under pressure from other spores in the same smut ball. They are quite smooth, but their contents appear more or less granular. In size they are almost like the spores of corn smut. Their germination is similar to the latter, or to any of the covered smuts described.

Infection and control.—When a smutted crop is threshed, the spores are liberated from the smutted heads and contaminate the seed. When such seed is sown, the spores germinate and infect the millet seedlings.

The usual formalin sprinkle treatment, as described for wheat bunt, is also effective in the control of millet smut. It has been found that $\frac{3}{4}$ to 1 gallon of solution is sufficient to sprinkle 1 bushel of seed. Since the seed germinates very rapidly when wet, it should be covered for only two hours after treatment, and then quickly dried. Sprouted seed should be sown immediately and not allowed to dry. It is advisable to use only seed of high vitality, since formalin seriously reduces the germination of weak seed.

SMUT OF *PANICUM* MILLETS

(Fig. 18)

The smut of *Panicum*, or broom-corn millets, occasionally causes some damage to hog millet in Western Canada. This smut is caused by the fungus *Sorosporium Panici-miliacei.* It is closely related to the fungi belonging to the genus *Ustilago,* but the spores, instead of occurring singly as in the latter, are bound together into small groups called spore-balls. This is the fourth genus to be mentioned in this bulletin.

Appearance in the field.—When a millet plant is smutted, the normal spreading panicle is completely destroyed. In its stead there appears a thick elongated boil often partly hidden by the upper leaf sheath. The smut-boil is at first covered by a white membrance which in time ruptures, and thereby exposes a

FIG. 18.—One healthy and three smutted heads of a cultivated *Panicum* millet.

black or brown, powdery, spore-mass. The affected plants are, therefore, easily recognized. It appears that most of the spores are scattered by wind and insects before harvest time and, in this way, reach the grain of healthy plants.

Appearance and germination of the spores.—The spores (fig. 14; 4) of the *Panicum* millet smut are united at first in groups called spore-balls, but when the spores are ripe they separate readily from one another. The smooth spores are almost as large as the spores of the corn smut fungus. The germination of the spore is similar to that already described for loose smut of oats.

Control.—The smut of *Panicum* millets is readily controlled by the formalin sprinkle treatment. Details of the treatment are the same as given for wheat bunt. From $\frac{3}{4}$ to 1 gallon of formalin solution is sufficient to treat 1 bushel of grain. The seed requires to be covered for only two hours. It is then spread out and dried as quickly as possible to prevent germination. Sprouted seed should not be allowed to dry, but should be sown immediately. Here also only seed of high vitality should be used, on account of the greater injury of formalin to weak seed.

OAT GRASS SMUT

Oat grass (*Arrhenatherum elatius*) is occasionally cultivated in Canada as a forage crop. As it has been found smutted in the cultivated state in Quebec and in British Columbia, the smut will be briefly described.

Oat grass smut is caused by *Ustilago perennans* Rostr., a fungus closely resembling the organism that causes naked smut of oats, and by some writers included under *Ustilago Avenae.*

Only the heads are affected with the smut. These are dwarfed and more erect than the healthy heads. The smut is confined mostly to the lower and inner part of each spikelet, differing in this way from the naked smut of oats, in which every spikelet is almost completely destroyed. Like other smuts that attack perennial plants, the mycelium is perennial in the underground portions and infects all the new shoots which are produced.

Although no experiments have been reported on the control of this smut by seed treatment, the formalin sprinkle treatment is suggested. As formalin injures the germination of seed of low vitality, only seed showing high germination should be treated.

KERNEL SMUTS OF SORGHUM

Depending on the purpose for which sorghum is grown, the different varieties may be divided into three types: the sweet sorghums, grown for syrup and forage; the grain sorghums, for grain and forage; and the broom corns, for seed or for the brush used in the manufacture of brooms. The annual loss in the United States from sorghum smuts, of which the kernel smuts are the most important, is estimated at $3,000,000.[55]

In Canada sorghum is not grown to any extent, but, wherever it has been grown, some smut has been observed in the crop. Some years ago a number of varieties of broom corn were tested at the Central Experimental Farm and at some of the branch Farms. In the first year of the experiment the seed was untreated and some varieties showed from 30 to 40 per cent of the plants affected with kernel smut.

Losses from kernel smut are not limited merely to the destruction of the grain. When sorghum is grown for fodder the quality of the fodder is lowered.

[55] Reed, G. M. U.S.D.A. Dept. Bul. 1284. 1925.

In the broom corns the smut stimulates the plant to produce a short curved brush with a central axis prominently developed which renders the brush useless for manufacturing purposes.

The three smuts of sorghum may be readily distinguished from each other by comparing the brief description of the kernel smuts as given in this section with that of the head smut in the next section.

Appearance of the disease.—An infected sorghum plant is quite normal in size and general appearance, and the presence of the disease can be recognized only when the head emerges from the sheath. The normal kernels are replaced by elongated protruding smut balls covered with a thin membrane. In the loose kernel smut the membrane ruptures easily and the spores thus set free are soon dispersed by the wind. In the covered smut, on the other hand, the membrance is tougher and less easily ruptured and spores are consequently not liberated from the smut-ball until the crop is threshed.

Causal organisms.—As already intimated there are in reality two kernel smuts of sorghum, the covered and the loose, caused by two closely related fungi, *Sphacelotheca Sorghi* (Lk.) Clinton, and *Sphacelotheca cruenta* (Kühn) Potter. The genus *Sphacelotheca* is the fifth to be described in this bulletin, and is evidently closely related to *Ustilago*, as the germination of their spores is very similar. The two genera are, however, distinct, for in *Sphacelotheca* the spores are borne around an elongated central columella or axis of host tissue and the smut-balls are covered with a false membrane of definite fungus cells. The covered kernel smut of sorghum is illustrated in fig. 17; a.

Seed treatment.—The kernel smuts of sorghum are easily controlled by seed treatment. The copper carbonate treatment, as described for wheat bunt, is most satisfactory. When copper carbonate containing 50 per cent copper is used, 2 ounces of dust per bushel is sufficient. If the copper carbonate has been diluted till it contains only 20 per cent copper, 4 ounces are required. Formalin also gives good results, but it invariably causes some seed injury, if the seed is immature, cracked, or slightly injured in threshing. If formalin is used 1 pound of formalin is mixed with 30 gallons of water. The seed is soaked for 1 hour in this solution, and then spread out to dry.

HEAD SMUT OF SORGHUM

Head smut of sorghum is not as prevalent as the kernel smuts, but, since at present no satisfactory way to control the disease is known, it is much more to be feared.

Head smut occurs not only in sorghum but also on corn. As yet it has not been found on either host in Canada.

Head smut is caused by *Sorosporium Reilianum* (Kühn) McAlpine, which is closely related to *Sorosporium Panici-miliacei*, the fungus causing *Panicum* millet smut. The genus differs from *Ustilago* in having its spores united into spore balls; the spores, however, of both genera germinate in a similar manner.

Appearance of the smut.—On sorghum the appearance of the head smut is very characteristic. The entire inflorescence is affected and is converted into an elongate boil much smaller than the normal inflorescence and covered by a transient whitish membrane. No difference is noticeable between healthy and infected plants until after the heads appear. The spores are interspersed with string-like remains of the vascular fibres of the head. When the membrane breaks the spores are rapidly blown away, and the string-like fibres alone remain.

FIG. 19.—Onion smut. (Photo. B. T. Dickson.)

In corn the smut is first observed in the tassel. This is converted into a mass of smut, or it may enlarge forming leaf-like structures. The ear is commonly converted into a mass of smut enclosed by the husks. Usually, when the tassel is affected, the ears are also destroyed. The smutted plants are stunted and remain green somewhat longer than normal plants. The smut-masses are enclosed in a delicate pinkish membrance which ruptures and exposes the spores.

Appearance and germination of the spores.—The spores are brown, spherical, about the size of corn smut spores, and finely verrucose (warty). They are united into spore-balls, which are firm at first, but later readily break up. The spore-balls are globose to oval and are about ten times the size of the spores. On germination the spore produces a four-celled promycelium on which conidia develop. Under favourable conditions the conidia bud abundantly forming a large number of secondary conidia.

Infection.—It is thought that spores in the soil rather than seed-borne spores are the chief source of infection. Infection apparently can take place only while the plant is still quite young.

Control.—Head smut cannot be controlled by seed treatments, but the amount of infection may be reduced by sanitary practices as recommended for corn smut, such as removing and destroying infected plants in small fields, preventing as far as possible the smut from getting into the manure, through which it is carried back to the land, and rotating the crops.

ONION SMUT

Onion smut is the only smut of economic importance that remains to be described. All of the smuts previously discussed attack cereals and forage crops belonging to the grass family. The onion is a member of the lily family, and where it is grown on a large scale as a truck crop, it is frequently injured by smut. Onion smut was first observed in Massachusetts in 1857, and is apparently of American origin.

From the New England States it has spread to all the onion-growing regions of the Northern United States and into Canada. It is also known now in Europe and Japan.

Onion smut is a destructive disease, especially in areas where onions are grown intensively. As the organism causing onion smut can live saprophytically in the soil, it frequently happens that soil planted continuously to onions becomes more and more infected, until a profitable crop of onions can no longer be grown on it. For this reason many acres of land otherwise suited to onion growing are now devoted to less profitable crops. Although the disease can be controlled, by seed treatment, the cost is considerable and, therefore, the expense of raising onions on land where the disease is present is increased.

The only available estimate of loss from the disease is that given for 1918 by the United States. It was estimated that the loss due to onion smut amounted to 780,000 bushels. In Canada the disease has been observed in the provinces of Manitoba, Ontario, and Quebec. In the trucking area around Montreal it has become the limiting factor in the growing of onions.

Appearance in the field.—(Fig. 19.) Smut first apears in the young seedlings within two to three weeks after the seed is planted. The cotyledon or seed-leaf, which is the first to appear above ground, is slightly distorted and swollen instead of being perfectly straight as it is in a healthy plant. If the plant is held up to the light a few days later, one or more dense black elongated areas can be seen inside the leaf. If the attack is severe many of the weakened plants

damp off, or gradually shrivel and die. The greatest number of plants in an infected field die at this time; the rows become thinner and thinner until only a fraction of the seedlings that came up remain standing. On crushing a dead leaf between the fingers, it will be found to be filled with spores in the form of a black powder. If, on the other hand, the attack is mild, the plants do not die, and, with the development of the successive leaves, the disease may be sloughed with the cotyledon. Usually, however, smut will appear as long dark streaks in the succeeding leaves. Such plants remain stunted, the leaves being short, brittle, and distorted. The diseased plants continue to die in various stages of development throughout the summer. Very few produce bulbs of any size, and those that survive until the time of harvesting are usually rotted at the base. As the diseased plants grow the black smut pustules increase in size until they are several inches in length, or may extend throughout the entire leaf. As the leaf becomes old and dried up, the pustules split open and the spores fall out.

Cause of onion smut.—Onion smut is caused by *Urocystis Cepulae* Frost. We have already described two other smut diseases, flag smut of wheat and stem smut of rye, that are caused by other species of *Urocystis*.

How onion smut spreads.—The spores of the onion smut fungus are liberated by the rupturing of the smut pustules, or by the decay of the infected parts of the onion which have fallen to the ground. In the soil the spores may germinate at once, or they may remain dormant for a few weeks, or months, or even years before germinating. Upon germination the spores put out long slender branching tubes and, under favourable conditions, a mycelium may be formed that continues to grow for many years although onions are not planted in the same field. No sporidia or other spores are produced, but the mycelium may break up into short pieces, which may lie dormant for long periods, and then germinate on the return of favourable conditions. The soil becomes so infected with spores, mycelium, and these detached mycelial segments, that onions cannot longer be raised on it without measures being taken to control the smut.

Appearance and germination of the spores.—Under the microscope the dusty black mass from the leaves or bulbs is found to be made up of what appear to be single spores, but are in reality spore-balls (fig. 14; 2). In the centre of each spore-ball one, or occasionally more, brown, fertile spores are found. On the surface of this central cell are fifteen to forty smaller hemispherical cells or accessory sterile spores. These are transparent with a brownish tint.

Anderson[56] found that, when recently matured spores were germinated, there first developed a hyaline swelling which became as large as the fertile spore. The swelling then produced from one to eight germ-tubes, which formed a dense mycelium of much branched threads, but no sporidia were present. When spores were germinated some time after they were mature no hyaline swelling was formed, but the germ-tubes developed directly from the fertile spore.

Seedling infection.—Only very young seedlings are susceptible to onion smut. Infection takes place by the mycelium penetrating directly through the epidermis. It occurs mostly before the "knees" appear above the ground, and it practically ceases after the first green leaf emerges from the side of the cotyledon. The period during which the onion seedling is susceptible depends on its rate of growth, and varies from 17 to 24 days.

Control of onion smut.—Although a number of different methods of onion smut control have been tried, the formalin drip treatment is by far the most effective

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[56] Anderson, P. J. and A. V. Osmun. Mass. Agr. Exp. Sta. Bul. 221. 1924.

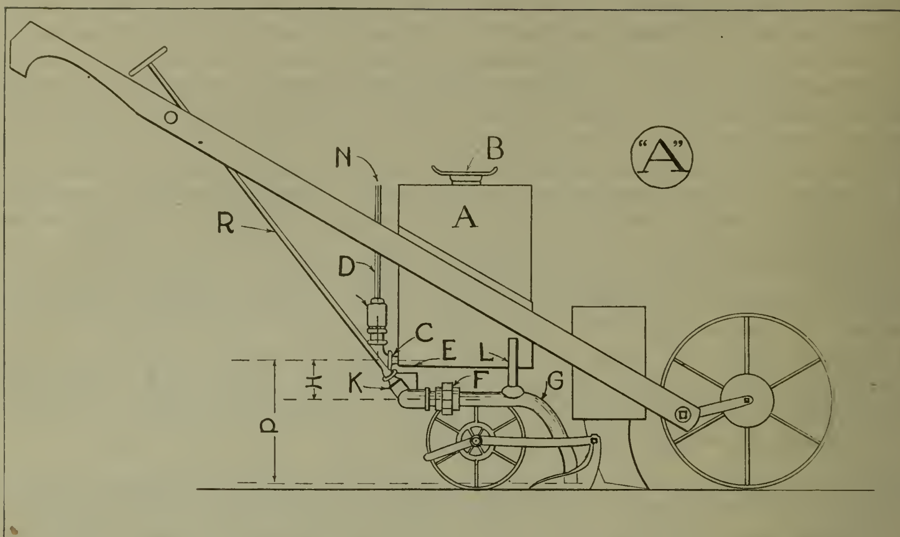
method as yet devised. There are, however, some objections to its use. A large amount of water is used in its application and consequently the amount of labour at planting time is greatly increased. Besides there is the danger of injury to the seed. With a view to reducing these objections to a minimum, Anderson and Osmun[56] have conducted extensive control experiments. They found that extreme dilutions, such as one part of formalin to 128 parts of water, involving the use of a large amount of water and extra labour, were not necessary under their conditions. The formalin injury varied inversely as the moisture content of the soil and directly as the concentration of the solution and the amount applied per unit length of row. Since seed injury always occurs when the smut is satisfactorily controlled, the formula of application should be so chosen as to give the most profitable, but not necessarily the maximum, control of smut. It should also be varied to meet the changing moisture conditions of soil. *If the soil is very dry, use the 1-50-5000 formula; if fairly moist, the 1-50-4000; and if wet, the 1-50-3000 formula.* The formula 1-50-5000 means that one pint of formalin is mixed with 50 pints of water and this amount of solution is applied to 5,000 feet of onion row. These formulae might be expressed in another way. Put one gallon of formalin into a 50-gallon barrel and fill to the top with water. If the soil is very dry apply at the rate of one barrel to one acre of onions (13 inches between rows). If the soil is mediumly moist, apply $1\frac{1}{4}$ barrels, and if wet and heavy, $1\frac{2}{3}$ barrels per acre. If the soil is dry the rate of seeding should be increased.

Method of application.—The formalin solution is applied to the row from a tank attached to the seeder. The most satisfactory machine so far devised for this purpose is one constructed by Anderson and Osmun[56], a cut of which is shown in fig. 20. A 14-quart cubical galvanized tank is attached between the handles of the drill behind the seed box. "The bottom of the tank is not flat, but has a slight slope to the lowest point at the rear, from which the solution is conducted through a $\frac{1}{2}$-inch pipe (E) to the stop cock (K) and to the union (F). From there it is led through a $\frac{3}{8}$-inch flexible block tin tube (G) and distributed on the soil just back of the seed-spout and in front of the coverers. The valve (K) is operated by a $\frac{1}{4}$-inch iron rod (R) from the rear of the handles. It has nothing to do with the regulation of the flow, but merely starts or stops the stream at the ends of the row, or wherever desired."

A screw cap (B) of 2-inch diameter, such as is commonly used on an automobile radiator, closes the opening in the top. When screwed down with the shoulder against a rubber washer the top is air-tight. A stand-pipe (D) parallel with and as high as the side of the tank is connected with an air-vent (C) by means of an elbow. In this way a uniform flow of solution is obtained irrespective of the height of the solution in the tank. If the tank, on the other hand, had a loose-fitting top, the flow would vary with the height of the liquid in the tank.

The tank is made still more reliable by the addition of two other important features. "In the enlarged base of the stand pipe there is a float (M), a light hollow brass cylinder with about one inch 'play' up and down. Attached to the top of the float is a slender brass wire which projects about an inch when the float is up and is flush with the top when it is down. When the stream is running from the tank and everything is in order the float is down." If the tank is not air-tight, due to a leak in the top of the tank, or from the operator forgetting to screw down the lid, the float remains up and the projecting stem warns the operator that something is wrong. The other feature is the small pipe (L) about 2 inches long inserted in the upper side of the outlet pipe. This pipe permits air to be admitted into the outlet pipe and prevents it filling com-

[56]Anderson, P. J. and A. V. Osmun. Mass. Agr. Exp. Sta. Bul. 221. 1924.



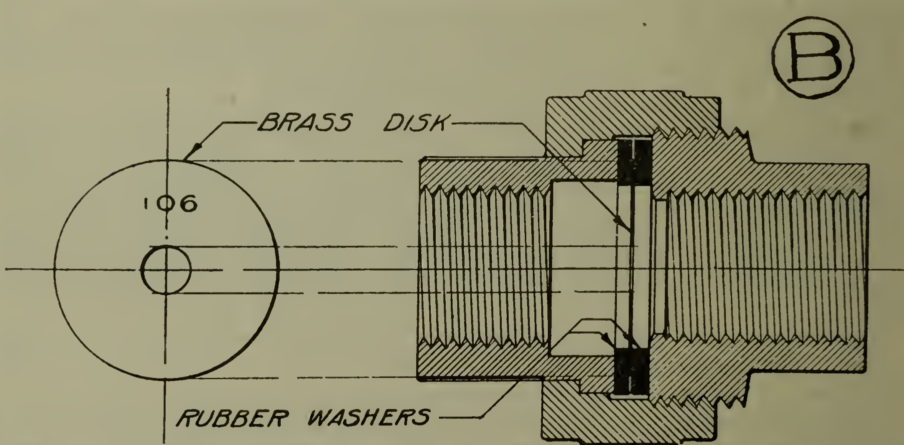


FIG. 20.—Tank for applying formalin drip treatment. "A". Drawing showing details of formalin tank construction. "B". Sectional view of union in outlet pipe, with disc and washers in place. (Both figures after Anderson and Osmun, Mass. Agr. Exp. Sta. Bul. 221, 1924.)

pletely with liquid when the valve is opened. Without this pipe the outlet pipe may or may not fill completely, with the result that two constant, but different, rates are possible. The additional pipe insures that only one rate of flow will occur.

" The rate of flow from the tank is regulated by a series of brass disks with central apertures of graded sizes. A disk is held in place between rubber washers in the union of the outlet of pipe (fig. 20, B). Any number of these simple brass disks may be quickly cut out with tin shears from a sheet of brass. A hole is drilled through the centre of each disk and this is enlarged with a rat-tail file to the proper size for the delivery of a gallon of solution in the previously calculated number of seconds, as the operator wishes. The number of seconds required to deliver a gallon of solution is then stamped on the disk" (fig. 20). The rate of delivery depends on the formula that is to be used and the rate at which the operator walks. In table 7 are given the number of seconds required to deliver one gallon for three different formulae at three rates of walking.

TABLE 7.—SHOWING THE NUMBER OF SECONDS REQUIRED TO DELIVER ONE GALLON OF SOLUTION WHEN THE FORMULA AND WALKING RATE ARE KNOWN

Formula[1]	Walking rate in feet per second		
	4	$4\frac{1}{2}$	5
	Secs.	Secs.	Secs.
1-50-3000	120	106	96
1-50-4000	160	142	128
1-50-5000	200	178	160

[1] The formula 1-50-3000 means one pint of formalin is mixed with 50 pints of water and this solution is applied to 3,000 feet of onion row. The walking rate of the workman must first be determined and the formula chosen, after which the number of seconds required to deliver a gallon may be read from the table. A disk that will deliver a gallon in that time can then be constructed.

The speed at which any given workman walks while pushing the loaded seeder can only be determined by trial. After his pace has been determined and the formula decided upon, it is an easy matter to calculate the rate of flow. Taking the speed of the workman as 4 feet per second and formula 1-50-3000, it would require 750 seconds to walk the 3,000 feet. Fifty pints are therefore to be delivered in 750 seconds, or one gallon in 120 seconds. The practical grower would probably only require two or three disks in any one season, and these can be made at the most convenient time.

This improved tank* takes care of all chances of error except one. Variation in the rate of application might arise from variation in the speed at which the workman pushes the drill. It has been found, however, that the speed of any individual workman is remarkably constant. More elaborate tanks might be devised that would deliver a constant quantity of liquid for a given distance without regard to the speed, but they would be too complicated and expensive for the grower.

* In a letter Dr. Anderson stated that, as far as he was aware, these tanks are not being manufactured, but a number have been made by local tinsmiths.

SUMMARY OF SEED TREATMENTS

Host	Smut	Seed Treatment recommended
Wheat	Bunt	1. Copper carbonate dust, 2 oz. per bush.; details of treatment, p. 23; or 2. Formalin, 1 lb. of formalin to 40 gals. of water; details of treatments, p. 31.
	Loose smut	Hot water, soak 4 hours at 86° F., 15-20 mins. at 112° F., 10 mins. at 124-127° F.; details of treatment, p. 38.
	Flag smut	1. Copper carbonate dust, 2 oz. per bush., p. 44; details of treatment, p. 23; or 2. Formalin, 1 lb. of formalin to 40 gals. of water, p. 44; details of treatment, p. 31.
Barley	Covered smut	Formalin, 1 lb. of formalin to 40 gals. of water, p. 46; details of treatment, p. 31.
	Loose smut	Hot water, soak 4 hrs. at 86° F., 15-20 mins. at 112° F., 10 mins. at 124-127° F., p. 47; details of treatment, p. 38.
Oats (common varieties)	Naked and covered smuts.	1. Formalin sprinkle, 1 lb. of formalin to 40 gals. of water, pp. 49 and 50; details of treatment, p. 31; or 2. Formalin spray, 1 lb. of formalin to 1 pint of water, pp. 49 and 50; details of treatment, p. 49.
Oats (hull-less varieties)	Naked and covered smuts.	Copper carbonate dust, 4 oz. per bush. (56 lb.), pp. 49 and 50; details of treatment, p. 23.
Rye	Stem smut	Formalin sprinkle, 1 lb. of formalin to 40 gals. of water, p. 53; details of treatment, p. 31.
Corn	Smut	No seed treatment; for control measures, see p. 55.
Western rye grass	Smut	Formalin immersion by dipping, 1 lb. of formalin to 40 gals. of water, p. 57; details of treatment, p. 32.
Timothy	Leaf smut	Formalin sprinkle or immersion by dipping, 1 lb. of formalin to 40 gals. of water, p. 58; details of treatment, pp. 31 and 32.
Fox-tail millets	Smut	Formalin sprinkle, 1 lb. of formalin to 40 gals. of water, p. 60; details of treatment, p. 31.
Panicum millets	Smut	Formalin sprinkle, 1 lb. of formalin to 40 gals. of water, p. 62; details of treatment, p. 31.
Oat grass	Smut	Formalin sprinkle or immersion by dipping 1 lb. of formalin to 40 gals. of water, p. 62 details of treatments, pp. 31 and 32.
Sorghum	Kernel smuts	1. Copper carbonate dust, 2 oz. of 50%, or 4 oz. of 20% copper carbonate, p. 63; details of treatment, p. 23. 2. Formalin, 1 lb. of formalin to 30 gals. of water, soak 1 hr., p. 63.
	Head smut	No seed treatment; for control measures, see p. 65.
Onion	Smut	Formalin drip, details of treatment, p. 66.

PART III

BOTANICAL DESCRIPTION OF THE SMUT FUNGI

The following guide* to the identification of the smut fungi referred to in this bulletin and their botanical descriptions may be useful to the agricultural teacher and student. The smut fungi belong to the order *Ustilaginales*. For North America, Clinton lists 11 genera with 133 species of the *Ustilaginaceae*, and 8 genera and 28 species of the *Tilletiaceae*. In Australia there are 68 species according to McAlpine. Of these 27 are common to both North America and Australia, but almost half of them have been introduced on the cultivated crop. For the world the number of smut fungi is estimated at 500 to 600 species. They occur on grasses, both cultivated and wild, and many other plants.

FAMILY 1—*USTILAGINACEAE*

Sori usually forming exposed dusty or agglutinated spore-masses. Germination by means of a septate promycelium, which gives rise to terminal and lateral sporidia (capable of yeast-like multiplication in nutrient solutions), or else to infection-threads.

Spores single.
 Sori (Spore-masses) dusty when mature:
  Without definite false membrane.................... I. *Ustilago*
  With false membrane of definite fungous cells........ II. *Sphacelotheca*

Spores in balls. which are often evanescent.
 Sori dusty or granular when mature, elongate, aborting the inflorescence.................................... III. *Sorosporium*

I. *Ustilago* (Persoon) Roussel, Fl. Calvador ed. 2:47. 1806

Sori on various parts of the hosts, at maturity forming dusty, usually dark-coloured spore-masses; spores single, produced irregularly in the fertile mycelial threads which entirely disappear through gelatinization; small to medium in size; germination by means of a septate promycelium producing only infection-threads or with sporidia formed terminally and laterally near the septa; sporidia in water usually germinating into infection-threads, but in nutrient solutions multiplying indefinitely, yeast fashion.

1. Spores perfectly smooth, small, 4-10µ in length. Sori in individual spikelets.
 (*a*) Spores lighter-coloured on one side.
  Hosts: *Avena;* spore-mass brown-black.................. 1. *U. levis*
  Hosts: *Hordeum;* spore-mass purple-black............... 2. *U. Hordei*
 (*b*) Spores uniformly coloured. Sori usually destroying inner and basal parts of the spikelet........................ 3. *U. Crameri*

2. Spores often apparently smooth, but at least granular under an immersion lens. Sori in spikelets, destroying only basal or inner parts .... 4. *U. bromivora*

3. Spores echinulate or verruculose (occasionally minutely or obscurely).
 (*a*) Spores small, 4-9µ in length.
  (1) Sori in spikelets rather completely destroying them.
   Hosts: *Avena*.................................. 5. *U. Avenae*
   Hosts: *Triticum*................................ 6. *U. Tritici*
   Hosts: *Hordeum*................................ 7. *U. nuda*
  (2) Sori destroying inner and basal parts.................... 8. *U. perennans*
 (*b*) Spores medium, 9-14µ in length.
   Sori on any part of the host........................... 9. *U. Zeae*
   Sori in striae in the leaves............................ 10. *U. striaeformis*

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* Adapted from:—
 Clinton, G. P. *Ustilaginales* North American Flora, Vol. 7, part 1, Oct. 4, 1906.
 McAlpine, D. The Smuts of Australia. 1910.

1. *Ustilago levis* (Kellerman et Swingle) Magnus, Abt. Bot. Ver. Prov. Brand. 37:69. 1896.
   Synonym—
   Ustilago Avenae levis Kellerman et Swingle.

Sori in spikelets, forming a black-brown adhering spore-mass, sometimes small and entirely concealed by the glumes, but usually evident, and destroying the inner and basal parts; spores lighter-coloured on one side, sub-spherical or rarely more elongate, smooth, 5-9μ. the most elongate rarely 11μ in length.
Covered smut of cultivated oats

2. *Ustilago Hordei* (Persoon) Kellerman et Swingle, Annual Rep. Kan. Agr. Exp. Sta. 2:268. 1890.
   Synonyms—
   Uredo segetum Hordei Pers.
   Ustilago Hordei tecta Jens.
   Ustilago Jensenii Rostr.

Sori in spikelets, forming an adhering purple-black spore-mass, about 6-10 mm. in length, covered rather permanently by the transparent basal parts of the glumes; spores lighter-coloured on one side, usually sub-spherical, or spherical, smooth, 5-9μ, the most elongate rarely 9-11μ.
Covered smut of cultivated barley.

3. *Ustilago Crameri* Körnicke; Fuckel, Jahrb. Nass. Ver. Nat. 27-28:11. 1873.
   Sori in the spikelets, infecting all of the spikes, ovate, about 2-4 mm. in length, chiefly destroying inner and basal parts; spores reddish-brown, chiefly ovoid to sub-spherical, though occasionally more elongate and irregular, smooth, with usually pitted contents, chiefly 8-11μ in length.
   Head smut of cultivated Fox-tail millets.

4. *Ustilago bromivora* (Tulasne) Fischer de Waldheim, Bull. Soc. Nat. Mosc. 40[1]:252. 1867.
   Sori in spikelets, infecting only the parts within the glumes, or destroying also the base of these, becoming dusty at maturity; spores usually reddish-brown, chiefly ovoid to spherical, but occasionally polyhedral or irregular, sometimes apparently smooth or only granular, but usually abundantly and minutely granular-verruculose. 6-13μ, usually averaging 9.5μ or above for spores from *Bromus*, and below 9.5μ for spores from *Agropyron*.
   Smut of certain cultivated brome grasses and western rye grass.

5. *Ustilago Avenae* (Persoon) Jensen, Charb. Céréales 4. 1889.
   Synonyms—
   Uredo segetum Avenae Pers.
   Ustilago segetum Avenae Jens.
   Ustilago Avenae f. foliicola Almeida

Sori in spikelets, forming a dusty olive-brown spore-mass, about 6-12 mm. long by half as wide, usually rather completely destroying floral parts, eventually becoming dissipated; rarely in leaves; spores lighter-coloured on one side, sub-spherical to spherical though often more enlongate, minutely echinulate, 5-9μ in length.
Naked smut of cultivated oats.

6. *Ustilago Tritici* (Persoon) Rostrup, Overs. K. Danske Vid. Selsk. Forh. 1890:15. Mar. 1890
   Synonyms—
   Uredo segetum Tritici Pers.
   Ustilago segetum Tritici Jens.
   Ustilago Tritici f. folicola P. Henn.
   Ustilagidium Tritici Herzb.

Sori in spikelets, forming a dusty olive-brown spore-mass, about 8-12 mm. long by half as wide, usually entirely destroying floral parts, and eventually becoming dissipated, and leaving behind only the naked rachis; spores lighter-coloured on one side, usually sub-spherical to spherical, occassionally more elongate, minutely echinulate especially on the lighter side, 5-9μ in length.
Loose smut of cultivated wheat and rarely of cultivated rye.

7. *Ustilago nuda* (Jensen) Kellerman et Swingle, Annual Rep. Kan. Agr. Exp. Sta. 2:277. 1890
   Synonyms—
   Ustilago Hordei nuda Jens.
   Ustilago Hordei Rostr.
   Ustilagidium Hordei Herzb.

Sori in spikelets, forming a dusty olive-brown spore-mass, about 6-10 mm. long by half as wide, temporarily protected by a thin membrane, but soon becoming dissipated and leaving the naked rachis behind; spores lighter-coloured on one side, minutely echinulate, sub-spherical to spherical or occasionally more elongate, 5-9μ in length.

Loose smut of cultivated barley.

8. *Ustilago perennans* Rostrup, Overs. K. Danske Vid. Selsk. Forh. 1890:15. 1890.

Synonyms—

Cintractia Avenae Ellis et Tracy
Ustilago Avenae (Pers.) Jens. according to McAlpine

Sori in spikelets, more or less destroying the basal and inner parts, sometimes even running down on pedicels, oblong, about 3.8 mm. in length, with dusty, olive-brown spore-mass; mycelium perennial in perennial parts of host; spores sub-spherical or spherical, occasionally ovate to ellipsoidal, usually lighter-coloured on one side, more or less minutely echinulate especially on the lighter side, 5-8μ in length.

Smut of cultivated oat grass.

9. *Ustilago Zeae* (Beckmann) Unger, Einfl. des Bodens 211. 1836.

Synonyms—

Lycoperdon Zeae Beckm.
Uredo Zeae Schw.
Ustilago Maydis Corda
Ustilago Schweinitzii Tul.
Ustilago Zeae-Mays Wint.
Ustilago Euchlaenae Arcang.
Ustilago Mays-Zeae Magn.

Sori on any part of the host, usually prominent, forming irregular swellings from a few mm. to over a dm. in diameter, at first protected by a sort of false white membrane composed of plant cells and semi-gelatinized fungous threads, soon rupturing and disclosing a reddish-brown spore-mass; spores ellipsoidal to spherical or rarely more irregular, prominently though rather bluntly echinulate, 9-11μ, the most elongate 15μ in length.

Common smut of cultivated corn.

10. *Ustilago striaeformis* (Westendorp) Niessl, Hedwigia 15:1. 1876.

Synonyms—

Uredo striaeformis Westend.
Tilletia de Baryana Fisch. de Waldh.
Tilletia striaeformis Oud.

Sori in leaves and sheaths, rarely in the inflorescence, short-linear or often extending for several cm., apparently by terminal fusion, also occasionally fusing laterally to cover most of leaf, at first covered by epidermis, but this soon ruptured and dusty brown-black lines of spores becoming scattered and leaves shredded; spores usually ellipsoidal to spherical, occasionally irregular, prominently echinulate, chiefly 9-14μ in length.

Leaf smut of cultivated timothy and other grasses.

II. *Sphacelotheca* De Bary, Verg. Morph. Biol. Pilze, 187. 1884.

Synonyms—

Sporisorium Ehrenb.
Endothlaspis Sor.

Sori usually in the inflorescence, often limited to the ovaries, provided with definite (more or less temporary) false membrane covering a dusty spore-mass and a central columella (usually chiefly of plant tissues); false membrane composed largely or entirely of definite sterile fungous cells which are hyaline or slightly tinted, oblong to spherical, and usually more or less firmly bound together; spores single, usually reddish-brown, developed in a somewhat centripetal manner, small to medium in size, germination as in *Ustilago*.

Spores olive or reddish-brown, smooth 5-8μ in length. Sori in ovaries.

False membrane covering the sori firm; sterile cells of the membrane breaking up into thread-like groups........ 1. *S. Sorghi*

False membrane covering the sori fragile; sterile cells of the membrane sub-spherical, separating readily into small groups or individual cells............................ 2. *S. cruenta*

1. *Sphacelotheca Sorghi* (Link) Clinton, Journal Mycology 8:140. 1902.

Synonyms—

Sporisorium Sorghi Link
Tilletia Sorghi-vulgaris Tul.
Ustilago Sorghi Pass.
Ustilago Tulasnei Kühn
Cintractia Sorghi-vulgaris Clinton

Sori usually in the ovaries or the essential organs, forming oblong to ovate bodies 3-12 mm. in length, rarely fusing the young spikelets into irregular forms, protected for considerable time by a false membrane, but upon rupture the olive-brown spore-mass becoming scattered, leaving naked the distinct columella of plant tissue; sterile cells of the membrane breaking up into thread-like groups; spores sub-spherical to spherical, smooth, contents often granular, usually averaging under 6μ in diameter.

Covered kernel smut of cultivated broom corn.

2. *Sphacelotheca cruenta* (Kühn) Potter, Phytopathology 2:98. 1912.

Synonym—

Ustilago cruenta Kühn

Sori usually in the ovaries or the essential organs, forming oblong to ovate bodies 3-12 mm. in length, rarely fusing the very young spikelets into irregular forms, covered by a thin delicate false membrane, which ruptures very early after the inflorescence emerges from the sheath, the olive-brown spore-mass becoming scattered, leaving naked the distinct columella of plant tissue; sterile cells of the membrane sub-spherical, larger than the spore, breaking up readily into small groups or individual cells; spores sub-spherical to spherical or irregular, smooth, contents often granular, usually averaging over 6μ in diameter.

Loose kernel smut of cultivated broom corn.

III. *Sorosporium* Rudolphi, Linnaea 4:116. 1829.

Sori in various parts of the host, forming dusty dark-coloured spore-masses; spore-balls composed of numerous fertile cells, often rather loosely united and frequently at maturity completely separating, of medium size; spores usually olive- or reddish-brown, of medium size; germination similar to that of *Ustilago,* sometimes with elongate germ-thread and no sporidia.

Sori aborting the inflorescence, very elongate.

Hosts: *Sorghum* and *Zeae* .... 1. *S. Reilianum*
Host: *Panicum*.. 2. *S. Panici-miliacei*

1. *Sorosporium Reilianum* (Kühn) McAlpine, Smuts of Australia 181. 1910.

Synonyms—

Ustilago Reiliana Kühn
Ustilago Reiliana f. Zeae Pass.
Ustilago pulveracea Cooke
Cintractia Reiliana Clinton
Sphacelotheca Reiliana Clinton

Sori very prominent, forming rather compact masses in the inflorescence, frequently involving it entirely, usually 5-15 cm. in length, at first enclosed in a pinkish or whitish membrane, which soon ruptures, and the black-brown spore-masses are dispersed, leaving behind ray-like remains of the columella; membrane consisting of the outer tissues of the host plant and sterile cells of the fungus, which form several layers of clear, more or less rounded cells, arranged in sub-spherical groups, also scattered through the spore-mass; spore-balls globose to oval or irregular, firm at first but afterwards readily separating, 80-112μ in length; spores globose to sub-globose, or sometimes slightly ellipsoid to ovoid, somewhat opaque, minutely but densely verruculose, 9-13μ in diameter.

Head smut of cultivated broom corn and cultivated corn.

2. *Sorosporium Panici-miliacei* (Persoon) Takahashi, Tok. Bot. Mag. 16:247. 1902.

Synonym—

Ustilago Panici-miliacei Wint.

Sori involving the entire inflorescence, elongate, covered with a dense layer of sterile hyphae and the epidermis of the host, which ruptures from the apex downward, disclosing black-brown spore-mass and shredded filaments of plant tissue; spore-balls irregular in shape, round to oval, or oblong, or polygonal, dark-brown, 50-100μ in length; spores yellowish-brown, sub-globose to angular or ellipsoid, smooth, 9-13μ in diameter.

Head smut of cultivated *Panicum* or broom-corn millets.

FAMILY 2.—*TILLETIACEAE*

Sori either forming dusty erumpent spore-masses, or else permanently imbedded in tissues. Germination by means of a short promycelium, which usually gives rise to a terminal cluster of elongate sporidia that, with or without fusing in pairs, produce similar or dissimilar secondary sporidia, or germinate directly into infection-threads.

Spores single, dusty at maturity............................... I. *Tilletia*
Spores in balls; sori dusty; spore-balls with sterile cortex..II. *Urocystis*

I. *Tilletia* Tulasne, Ann. Sci. Nat. III, 7:112. 1847

Sori in various parts of the hosts, usually in the ovaries, forming a dusty spore-mass; spores single, usually formed singly in the ends of the mycelial threads, that disappear more or less completely through gelatinization, of medium to large size; germination by means of a short promycelium, which usually gives rise to a terminal cluster of elongate sporidia that, with or without fusing in pairs, may, in nutrient solutions, give rise to a considerable mycelium bearing secondary air-sporidia.

Spores smooth .... 1. *T. laevis*
Spores reticulate .... 2. *T. Tritici*

1. *Tilletia laevis* Kühn, Hedw. 12:152. 1873.

Synonyms—
Ustilago foetens B. & C.
Tilletia foetens Trel.

Sori in ovaries, ovate or oblong, 5-8 mm. in length, more or less concealed by the glumes, all or only part of the ovaries of a spike infected; spores light- to dark-brown, oblong to chiefly sub-spherical or spherical, occasionally somewhat angular, foetid especially when young, smooth, chiefly 16-22μ, the most elongate rarely 28μ in length.
Smooth-spored stinking smut of cultivated wheat.

2. *Tilletia Tritici* (Bjerkander) Winter; Rab. Krypt. Fl. 1:110. 1881.

Synonyms—
Lycoperdon Tritici Bjerk.
Uredo Caries DC.

Sori in ovaries, ovate to oblong, 5-8mm. in length, more or less concealed by the glumes; sterile cells few, hyaline, sub-spherical, with medium thin wall, smaller than spores; spores chiefly sub-spherical or spherical, light- to dark-brown, with winged reticulations about 1μ high by 2-4μ wide, 16-22μ in diameter.
Rough-spored stinking smut of cultivated wheat.

II. *Urocystis* Rabenhorst; Klotzsch. Herb. Viv. Myc. ed. 2:393. 1856

Synonym—
Polycystis Lév.

Sori usually in the leaves or stems, occasionally in other parts, producing dark-coloured. usually dusty spore-masses; spore-balls prominent, compoed of an enveloping cortex of tinted sterile cells and usually one to several interior fertile cells, or small or medium size; spores generally dark-coloured, variable. of medium size; germination by a short promycelium, producing terminally grouped sporidia, which give rise to similar secondary sporidia, or to infection threads.
Sori in leaves, petioles, or stem.

Spores usually 1, rarely 2 in balls; cortical cells 6-10μ, rarely 12μ .... 1. *U. Cepulae*
Spores usually 1 or 2, rarely 3 or 4, in balls.
Spore often incompletely invested by oval sterile cells; host: *Secale*.................................... 2. *U. occulta*
Spore usually completely invested by ellipsoidal to globose sterile cells; spore surface delicately punctulate; host: *Triticum* .... 3. *U. Tritici*

1. *Urocystis Cepulae* Frost; Farl. Ann. Rep. Soc. Mass. Board Agr. 24: App. 175. 1877.

Synonym—
Urocystis Colchici Cepulae Cooke

Sori in leaves, forming isolated pustules, or often affecting them for the greater part of their length and breadth sometimes occurring at their base in the bulbs, upon rupture of

covering membrane disclosing a dusty black-brown spore-mass; spore-balls ovoid to spherical, small, 17-25μ in length; sterile cells tinted, ovoid to spherical, small, rather completely covering the spores, usually 4-8μ in length; spores reddish-brown, ovoid to spherical, usually 1, rarely 2 in a ball, chiefly 12-16μ in length.

Smut of cultivated onion.

2. *Urocystis occulta* (Wallroth) Rabenhorst; Klotzsch, Herb. Viv. Myc. ed. 2:393. 1856.

Synonym—

Erisybe occulta Wallr.

Sori in leaves, leaf-sheaths, culms, and on glumes, forming linear striae usually of great length, at first covered by the leaden-coloured epidermis, then erumpent, exposing the powdery, black spore-balls; spore-balls globose, elliptical, or oblong, 16-32μ in length; sterile cells generally partially, but sometimes completely investing the spores, hyaline or yellowish tinted, oval, 6-10μ in length; spores dark golden-brown, spherical to oblong, 1-3 or occasionally 4-5 in a ball, 12-18μ in length.

Stem smut of cultivated rye.

3. *Urocystis Tritici* Körnicke, Hedw. 16:33. 1877.

Sori in leaves, leaf-sheaths, culms, and occasionally on glumes, forming elongated striae running parallel to one another, at first covered by the raised leaden-coloured epidermis, which gradually decays in patches, exposing the powdery, black spore-balls; spore-balls globose, ellipsoid, or oblong, bright golden-brown, 24-40μ in length; sterile cells usually completely investing spores, very pale yellow, ellipsoid to globose and bulging, 9-12μ in length; spores spherical or oval, 1-4 in ball, occasionally 5, 2-3 common, 12-16μ in length.

Flag smut of cultivated wheat.

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